

(Analysis Note #Run12pp510-xj2) Run12pp510GeV Single-Particle (Hadron and Muon) Yields Analysis and Monte Carlo Simulations

Xiaodong, Jiang updated on 10/26/2015

This analysis note covers details of **Run12pp510 Muon-Arm Data single-particle yields in gap2, gap3 and gap4**. Through single-particle Monte Carlo simulations, relative relations of hadron vs muon are extracted.

Data Samples and Event-Triggers used in this analysis:

- For Yield studies of particles stopped in gap2, gap3, gap4, **ERT triggered events are used** in this analysis (to avoid known problems in MUID1D trigger efficiency). (to mimic the Min-Biased triggered events, which were not available due to heavily pre-scaled).

All related information can be found at:

<https://www.phenix.bnl.gov/phenix/WWW/publish/xjiang/Run12/Run12pp510/>

Part-I Run12pp510 “MinBias Data” Analysis: Gap2, Gap3, Gap4 events and Relative Yield Ratios

Data set: lack of high statistic MinBias data set.

Used ERT triggered events to substitute as “MinBias”

MuID detector size caused lost of events at lastgap=2 and lastgap=3.

Required detector fiducial-cuts on MuTr and MuID, on both MC and data

Extracting background from single-particle spectra to obtain prompt-muon spectra

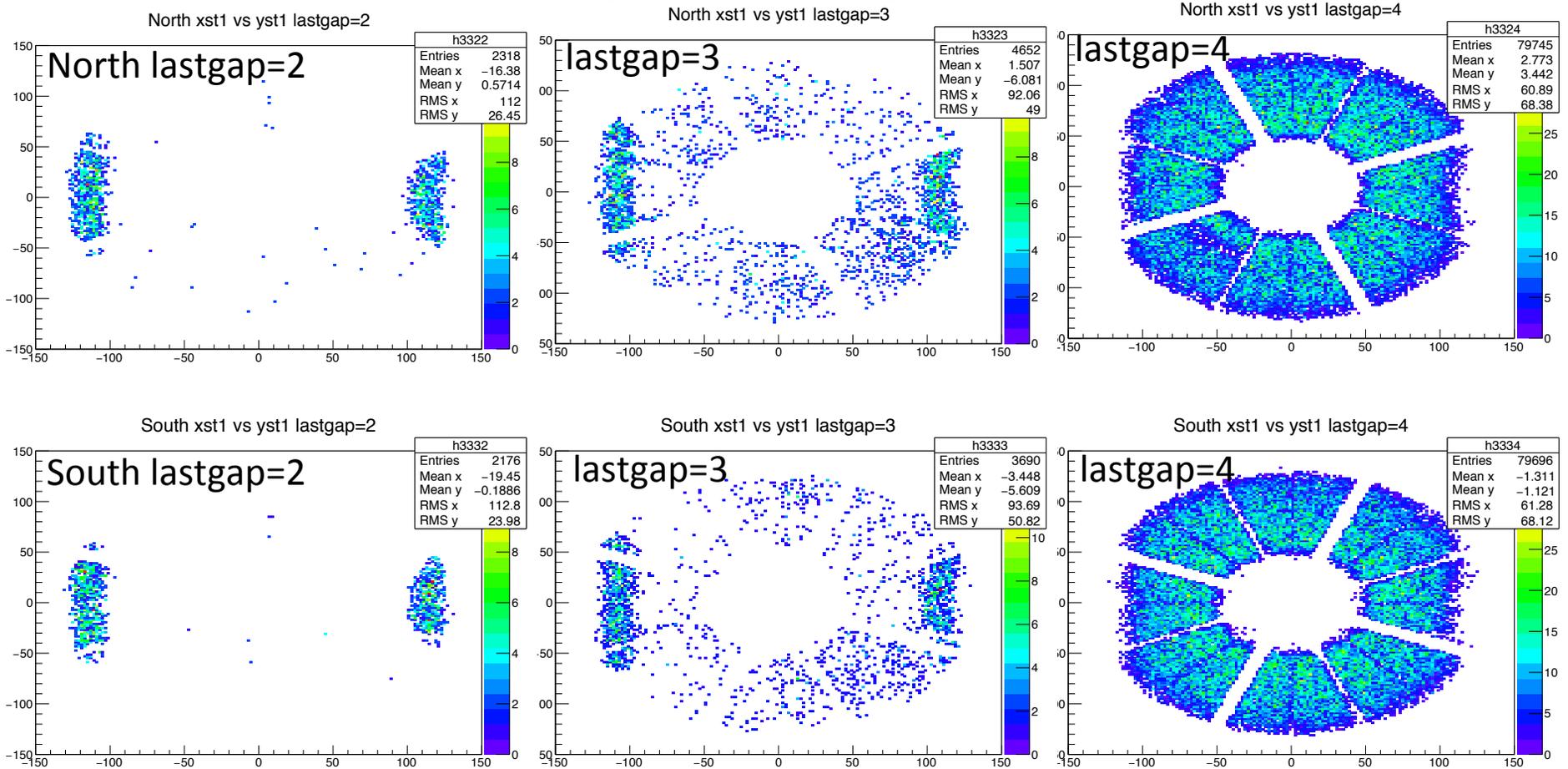
The Default procedures.

Simulation and results.

Analysis progresses.

Results from Simulations

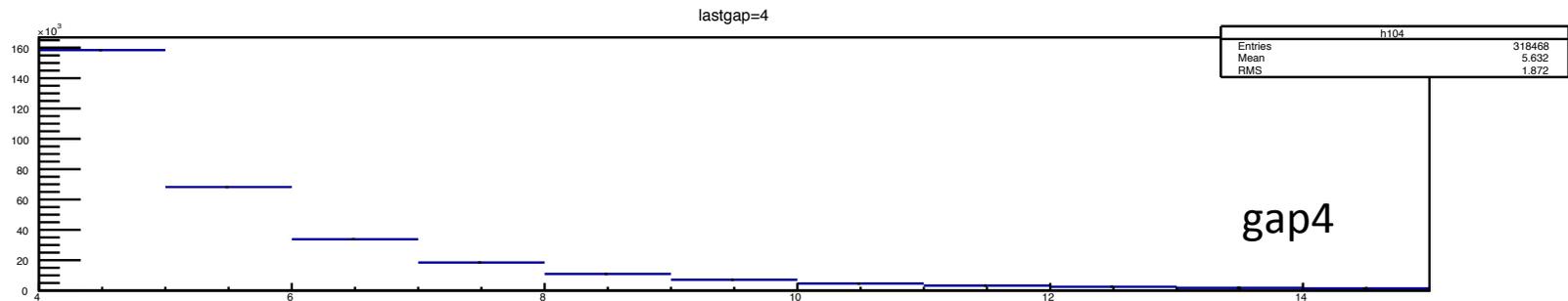
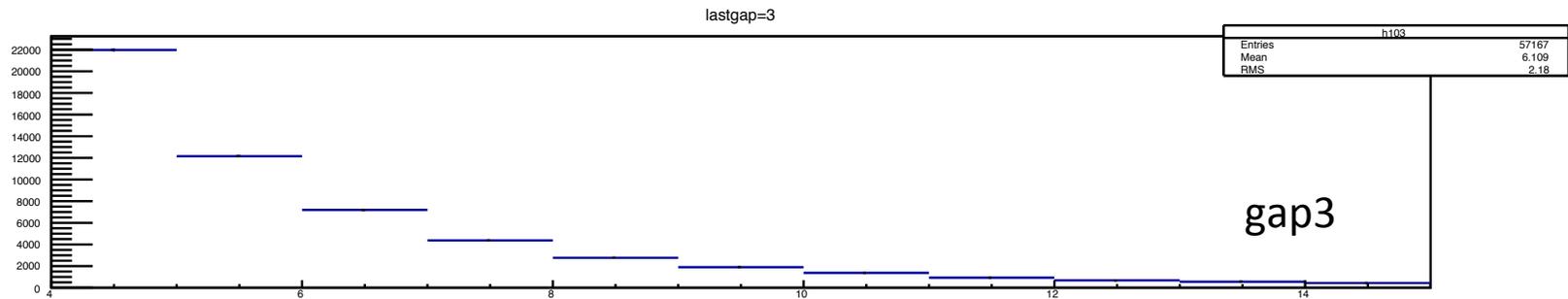
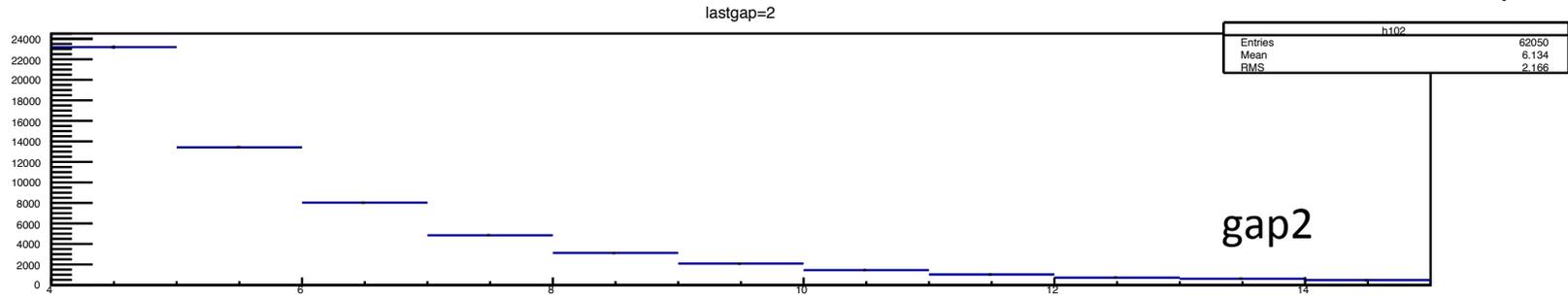
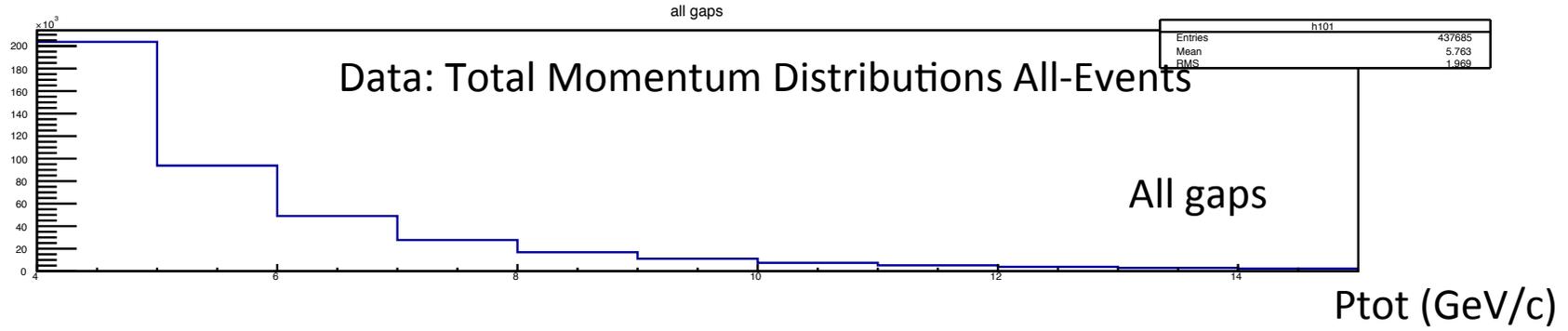
MC: track y (hor) vs x (vert) position at MuTr station-1

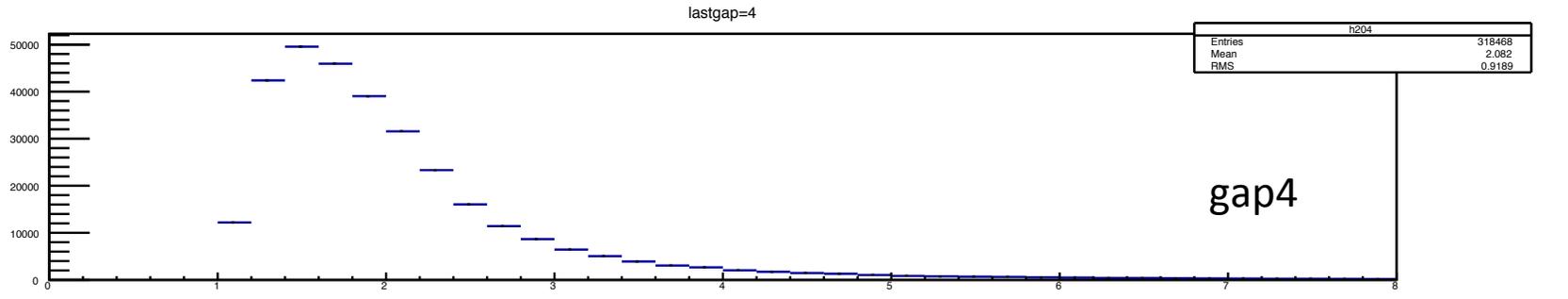
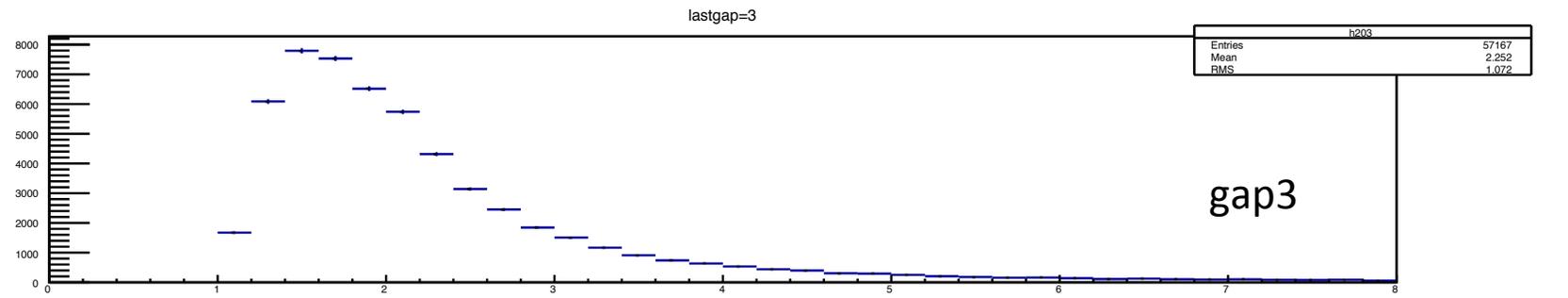
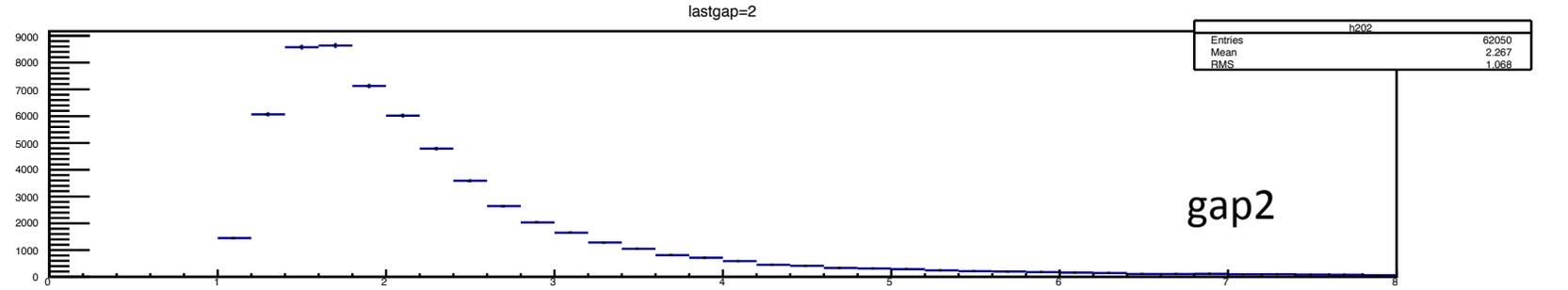
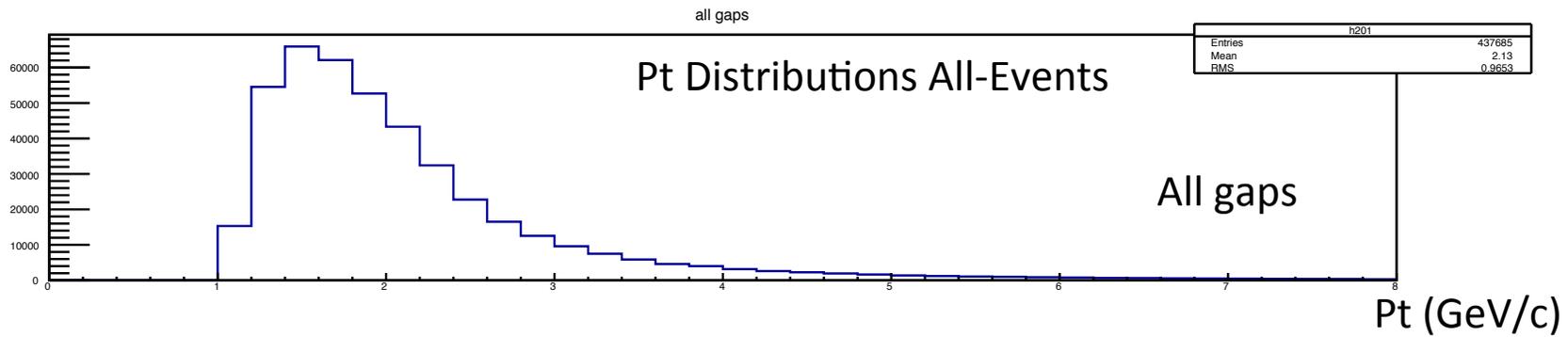


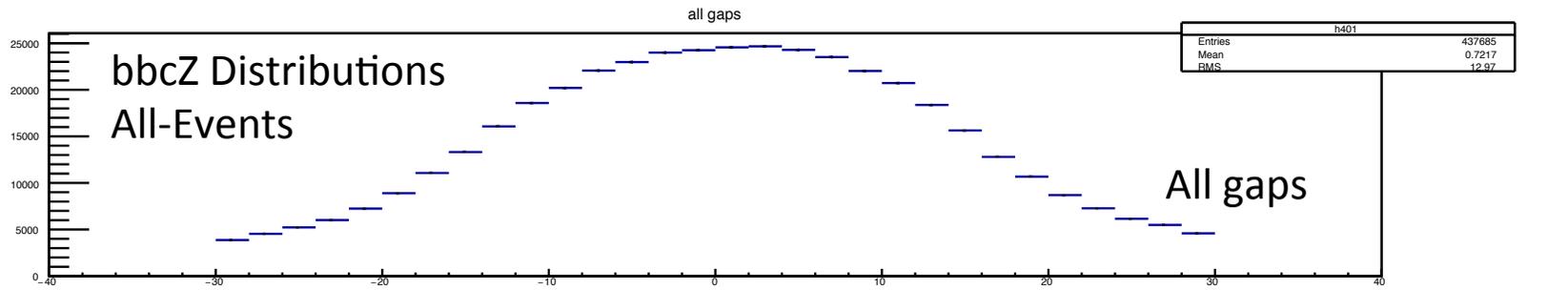
MuID detector size caused lost of events at lastgap=2 and lastgap=3.

Required detector fiducial-cuts on MuTr and MuID, on both MC and data

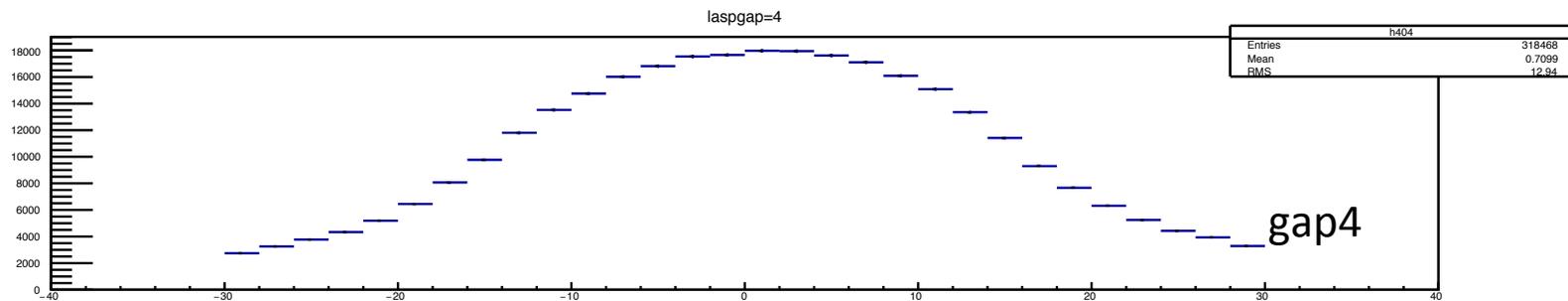
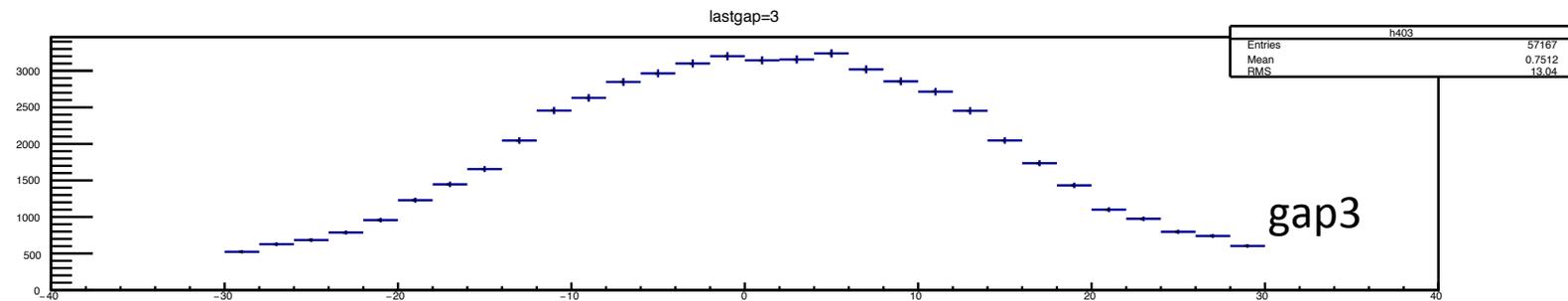
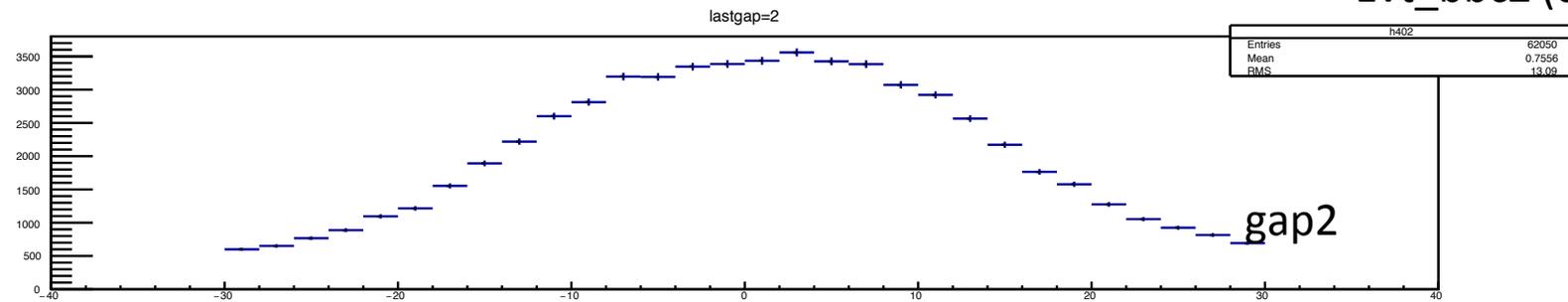
Data: Total Momentum Distributions All-Events

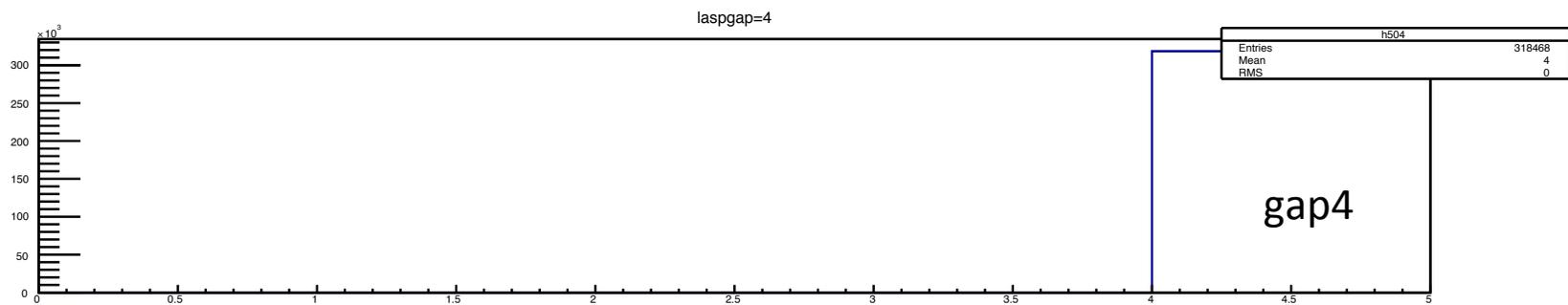
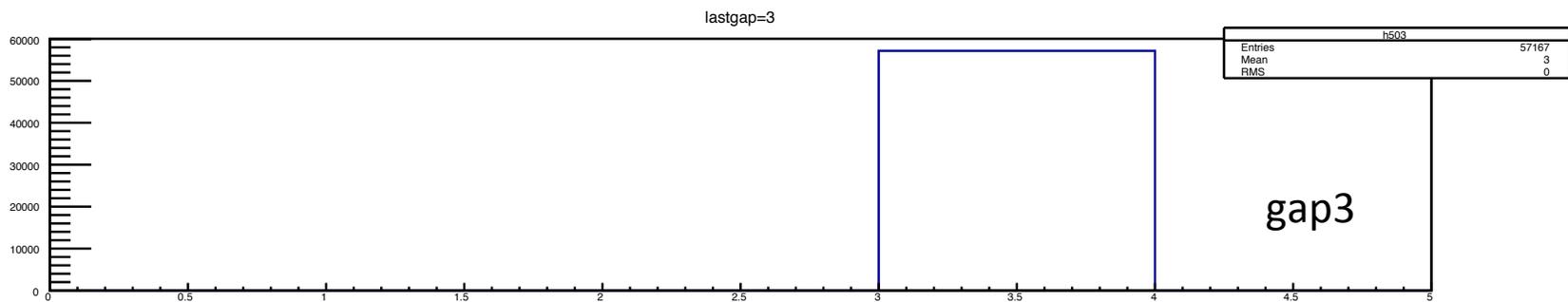
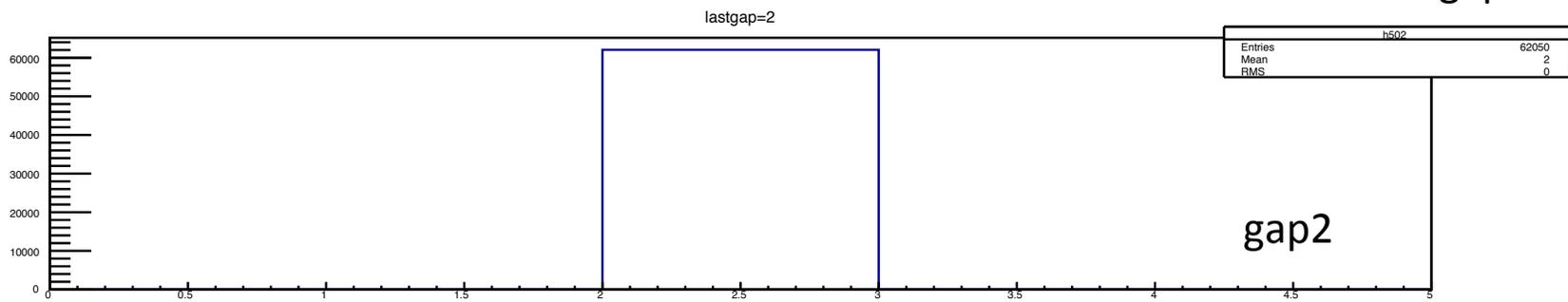
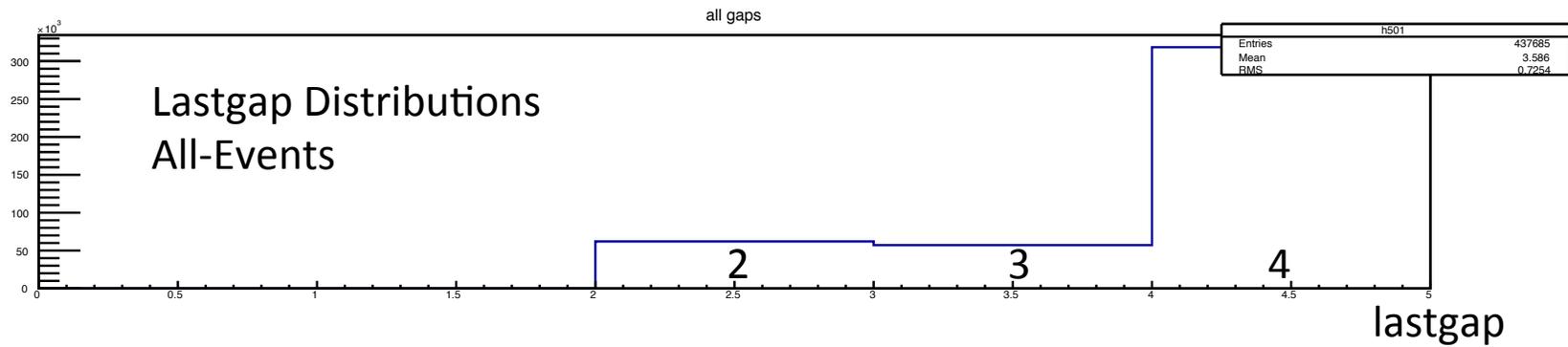






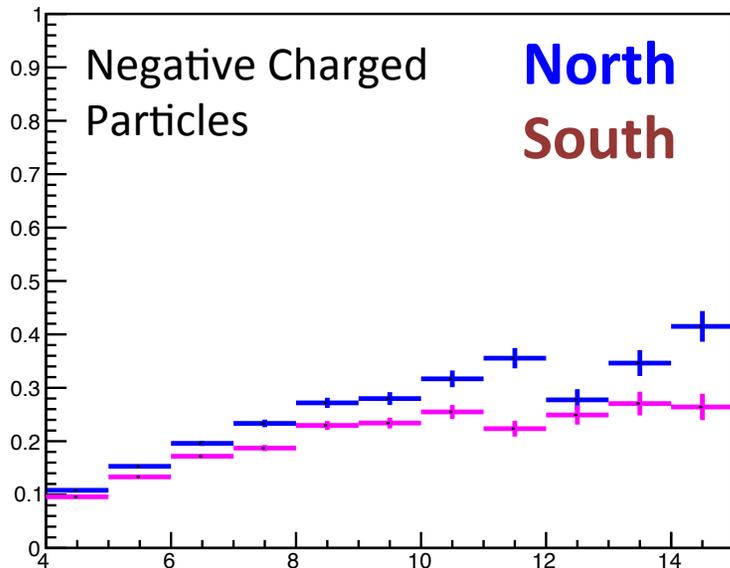
Evt_bbcZ (cm)



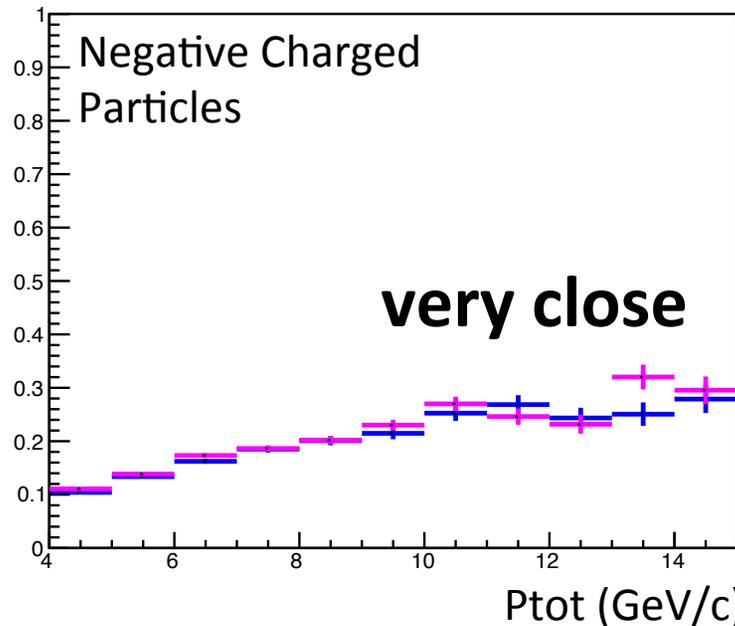


Ratios of gap2/gap4 and gap3/gap4 Compare North vs South

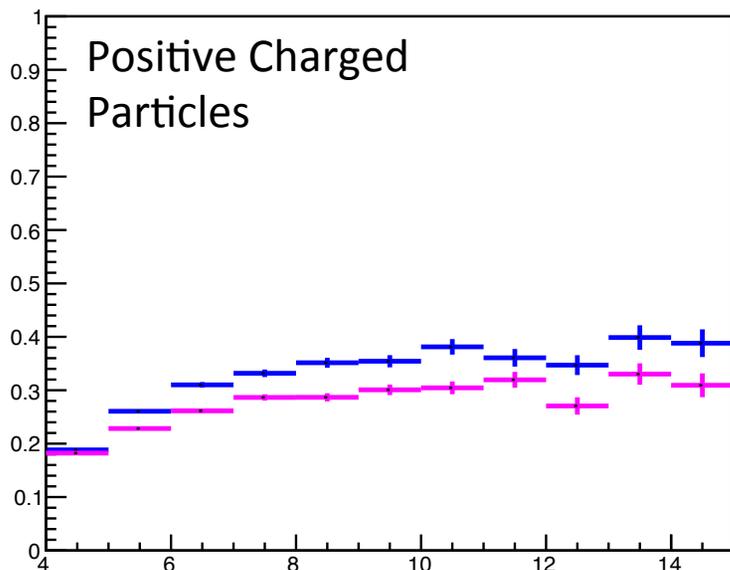
Charge -1 ratio gap2/gap4



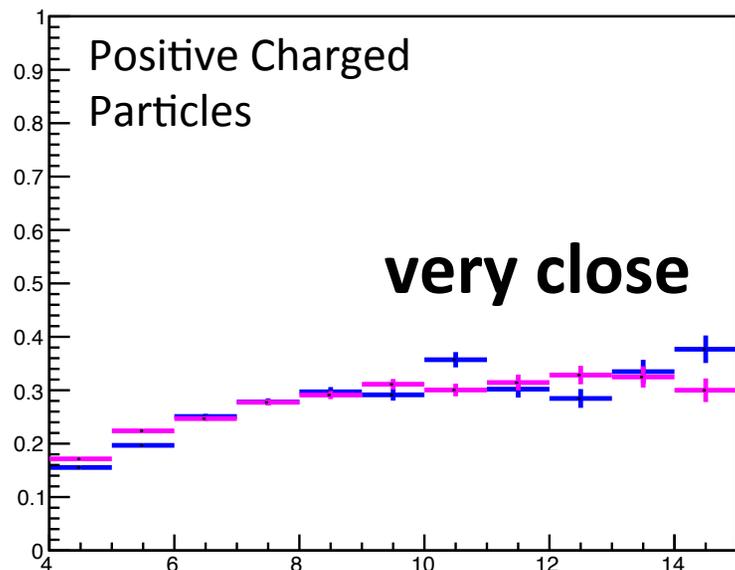
Charge -1 ratio gap3/gap4



Charge +1 ratio gap2/gap4

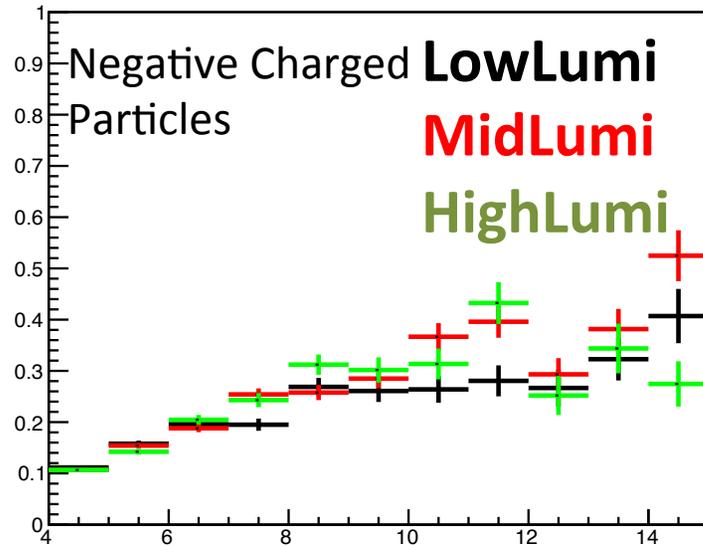


Charge +1 ratio gap3/gap4

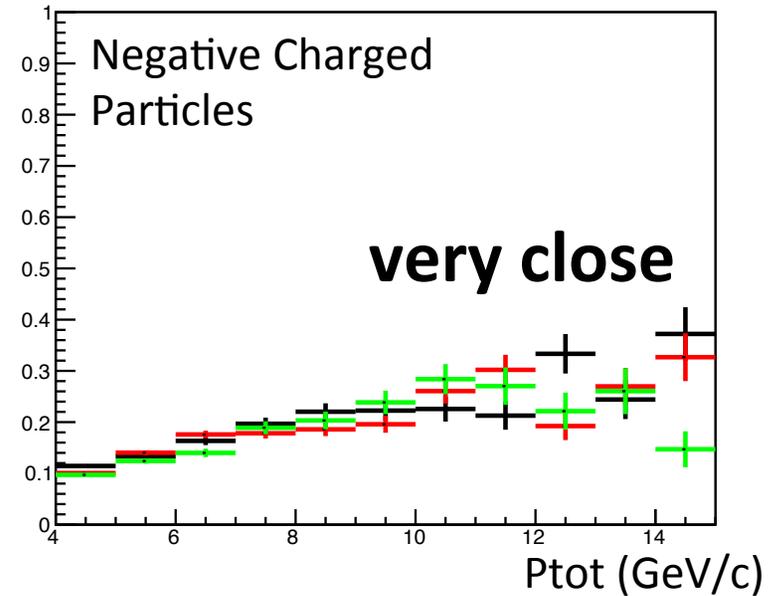


Ratios of gap2/gap4, gap3/gap4 for Different Luminosities: North Arm

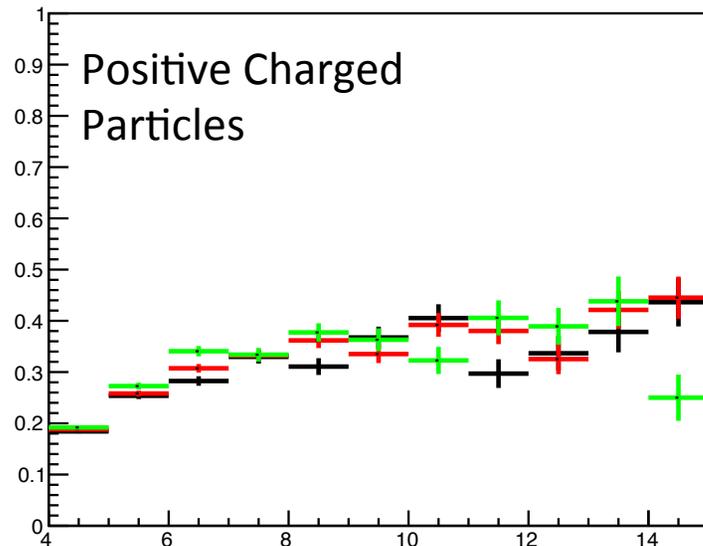
North Charge -1 ratio gap2/gap4



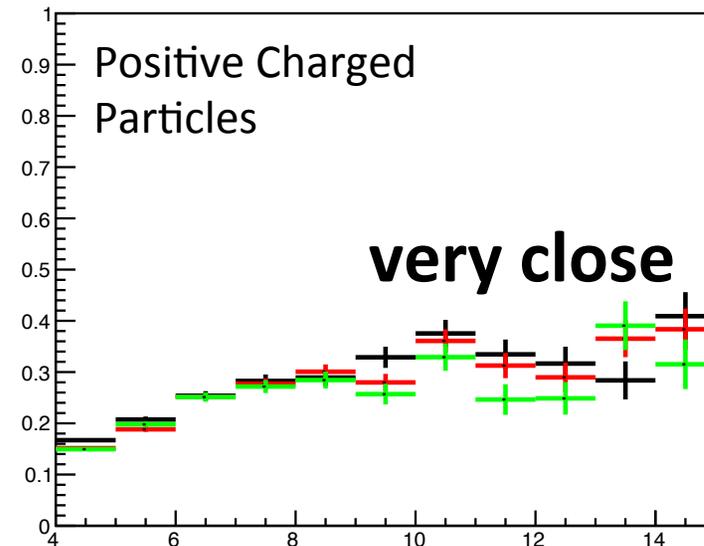
North Charge -1 ratio gap3/gap4



North Charge +1 ratio gap2/gap4

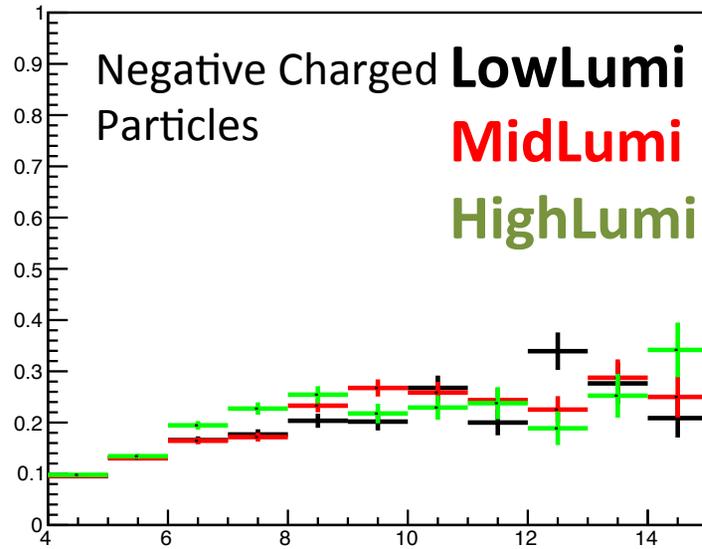


North Charge +1 ratio gap3/gap4

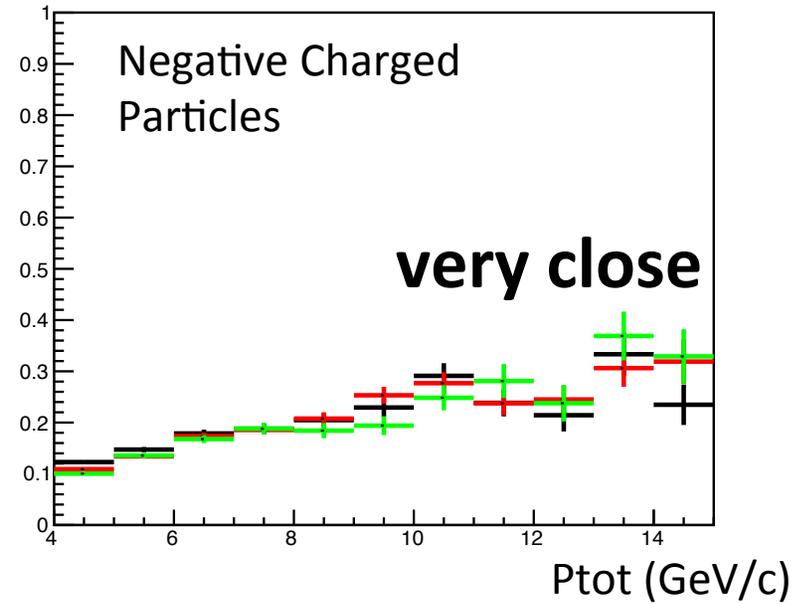


Ratios of gap2/gap4, gap3/gap4 for Different Luminosities: South Arm

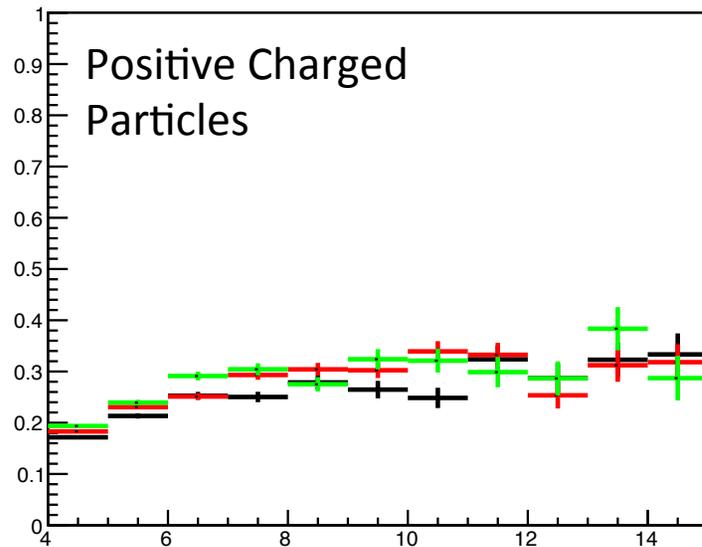
South Charge -1 ratio gap2/gap4



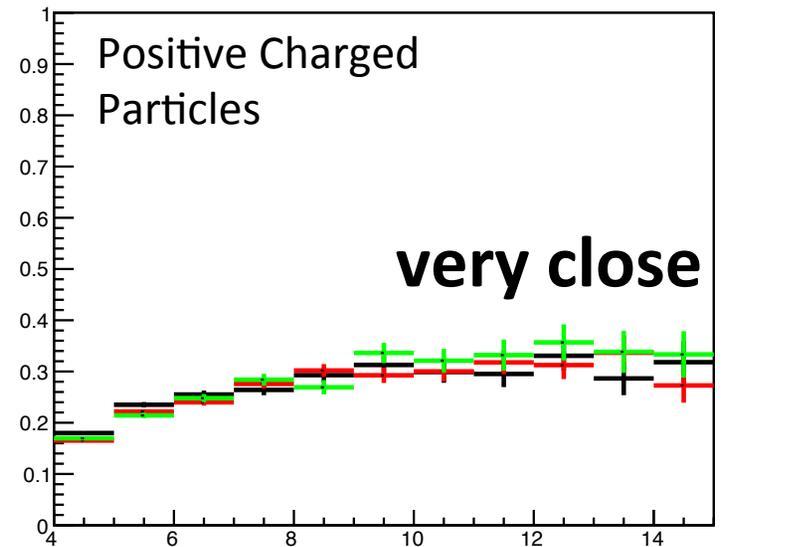
South Charge -1 ratio gap3/gap4



South Charge +1 ratio gap2/gap4



South Charge +1 ratio gap3/gap4



Conclusions on Gap Yield Ratios

within Statistical Uncertainties

Gap3/Gap4 Ratio:

Very Close. Between North-Arm and South-Arm.

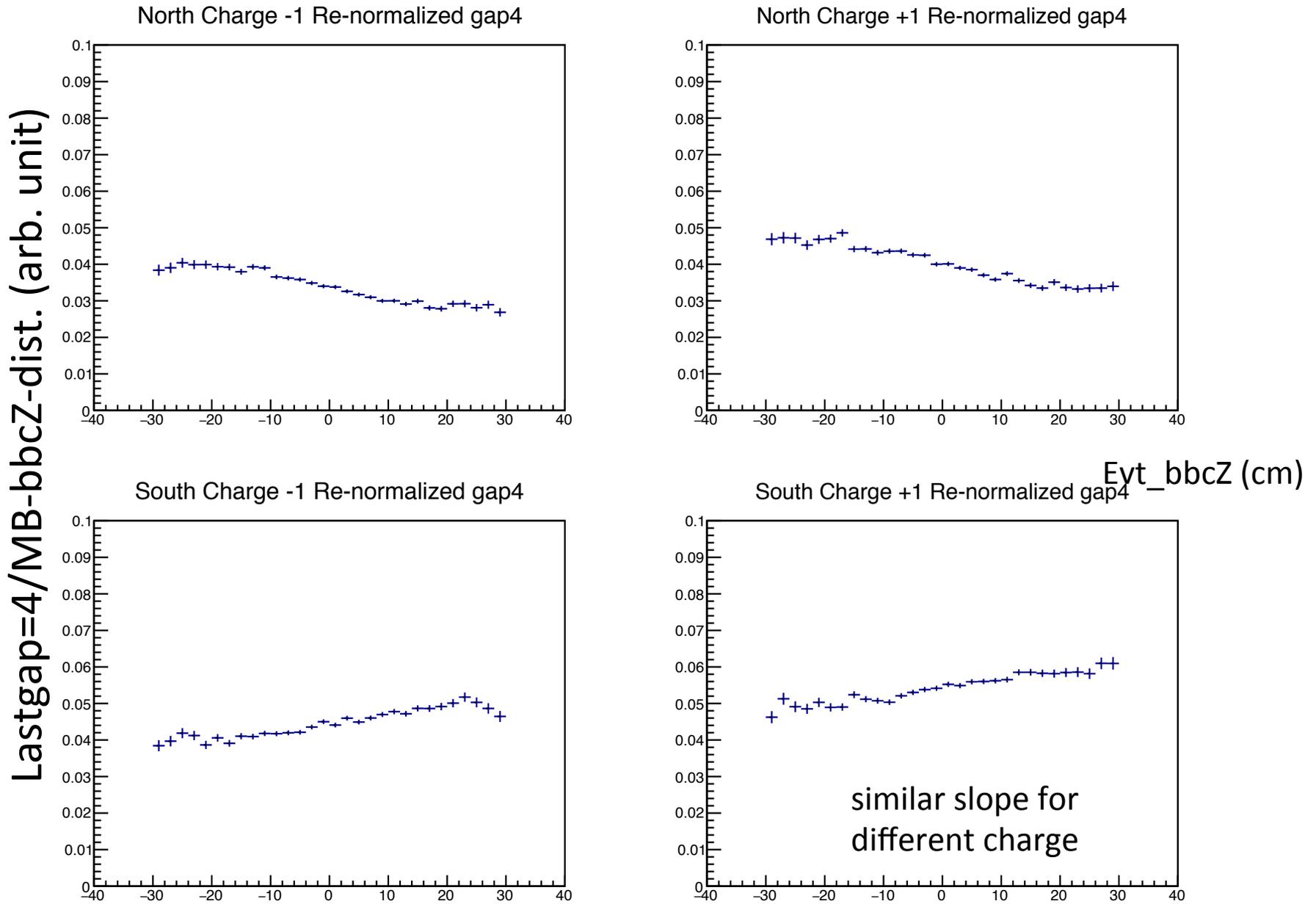
Very Close. Between run-groups with different luminosities.

Gap2/Gap4 Ratio:

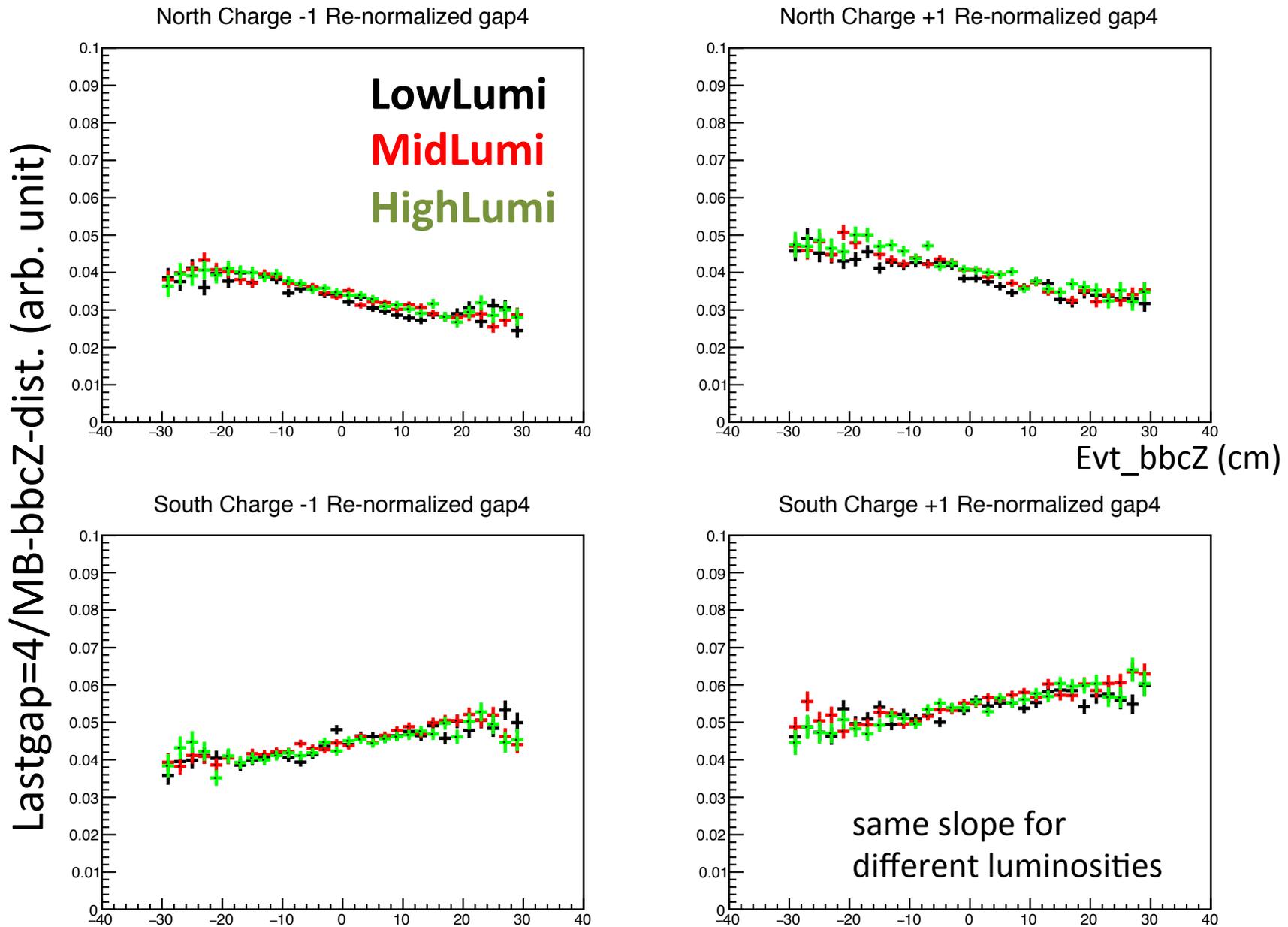
North vs South-Arm are different. Similar trends between charge -1, charge +1.

Runs-groups with different luminosities show small differences. South-Arm high-luminosity run-group has slightly higher gap2/gap4 ratios.

Lastgap=4 events re-normalized to bbcZ distribution of MB events



Lastgap=4 events re-normalized to bbcZ distribution of MB events



Part-II Monte Carlo Simulations

- single-muon simulations, using uniform momentum distributions (2.0-20.0 GeV/c).
- Momentum cuts.
- Slope of dN/dz for single-muon.
- Single-hadron simulations (pion and Kaon), using uniform momentum distributions (2.0-20.0 GeV/c).

Location of Simulation Directory

Flat momentum and angular distribution simulation, through GEANT4

Files, code and outputs at:

`/gpfs/mnt/gpfs02/phenix/spin3/xjiang/simulation/particleAcceptance/scripts`

Pythia8 simulation, files and code at:

`/gpfs/mnt/gpfs02/phenix/spin3/xjiang/simulation/particleAcceptance/scripts_MB`

Pure pythia8 MB simulation files:

`/gpfs/mnt/gpfs02/phenix/spin3/xjiang/simulation/MB/add_pythia8`

Results of Simulation-I

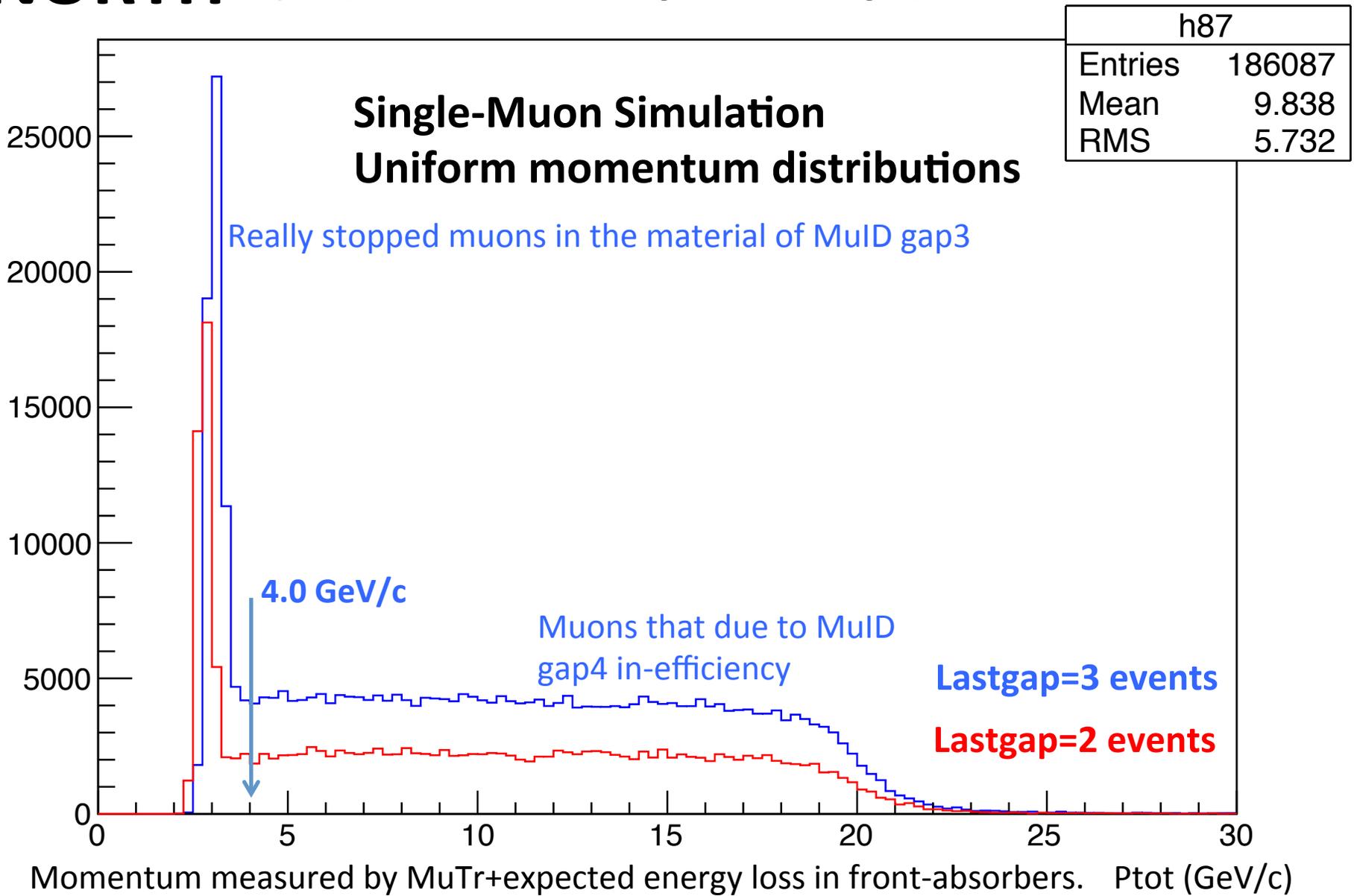
(with uniform momentum and angular distributions)

Uniform Events Generator -> Geant4 model -> Detector hits -> Track reconstruction
(MUID tube eff files corresponding to mid-Luminosity, run367161)

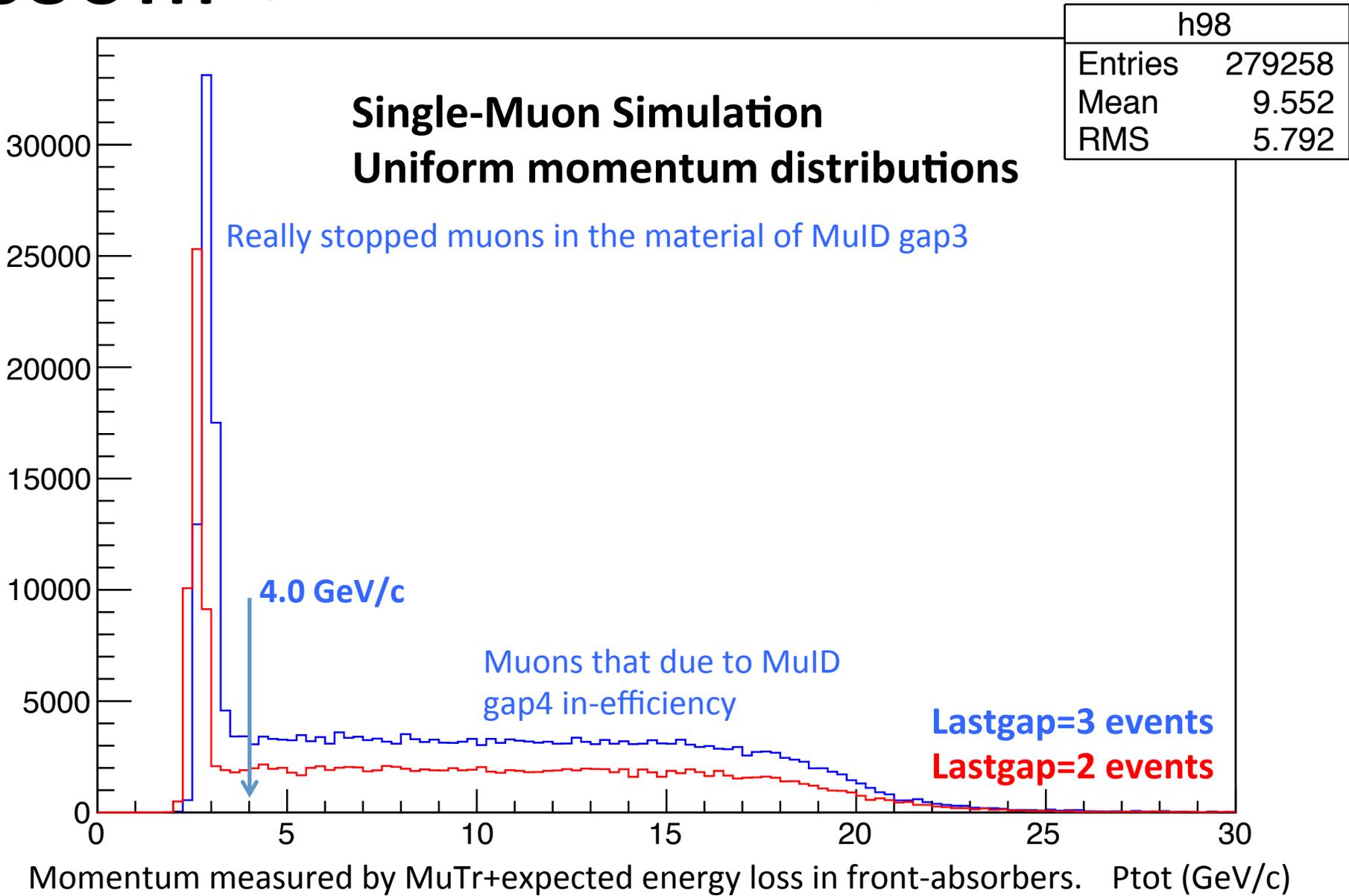
- Realistic Evt_bbcZ distribution, according to Run12pp510 data
- Random sampling of particle momentum, 1-20 GeV/c.
- 25 million events each for mu+, mu-, pi+, pi-, k+, k- (took ~3 weeks on rcf).
- Same cuts applied as in data analysis.

Obtained ptot (pt), bbcZ, spectra for events corresponding to lastgap=2, 3, 4 for each case.

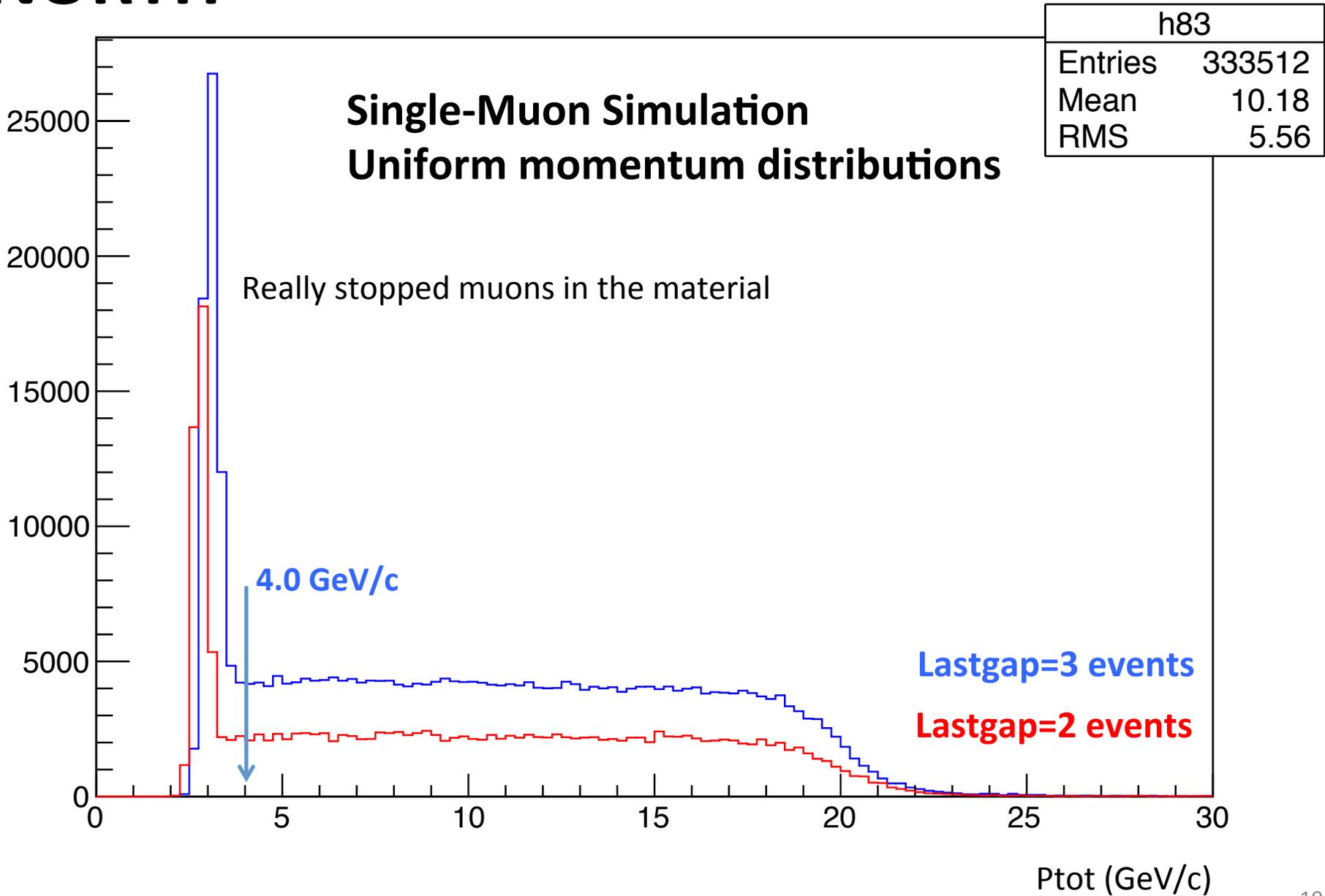
NORTH''+' ptot North Chage +1 lastgap=3 **Lastgap=2**



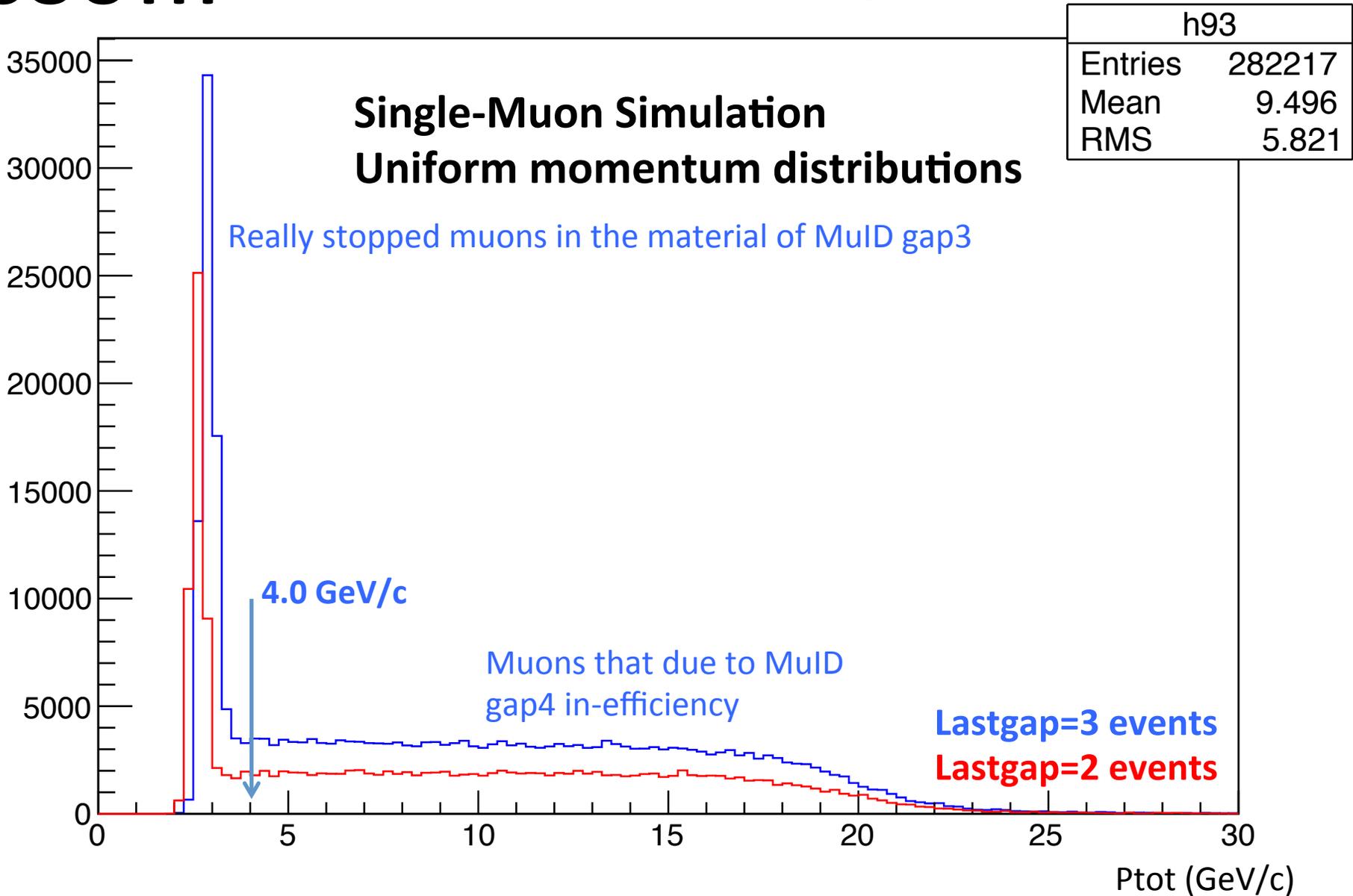
SOUTH''+''' ptot South Chage +1 lastgap=3 **Lastgap=2**



NORTH”-” ptot North Chage -1 lastgap=3 **Lastgap=2**



SOUTH”-” ptot South Chage -1 lastgap=3 **Lastgap=2**



From simulation: conclusions on total momentum cuts

If we wish to reject stopped muons in lastgap=3, lastgap=2 event samples, **a cut of $P_{tot} > 4 \text{ GeV}/c$ should be considered.**

A cut of $P_{tot} > 3.5 \text{ GeV}/c$ is “barely enough”, especially for North-arm, which has 10 cm extra steel in the back of MuTr magnet, compared to South-arm.

Single-Muon Simulations

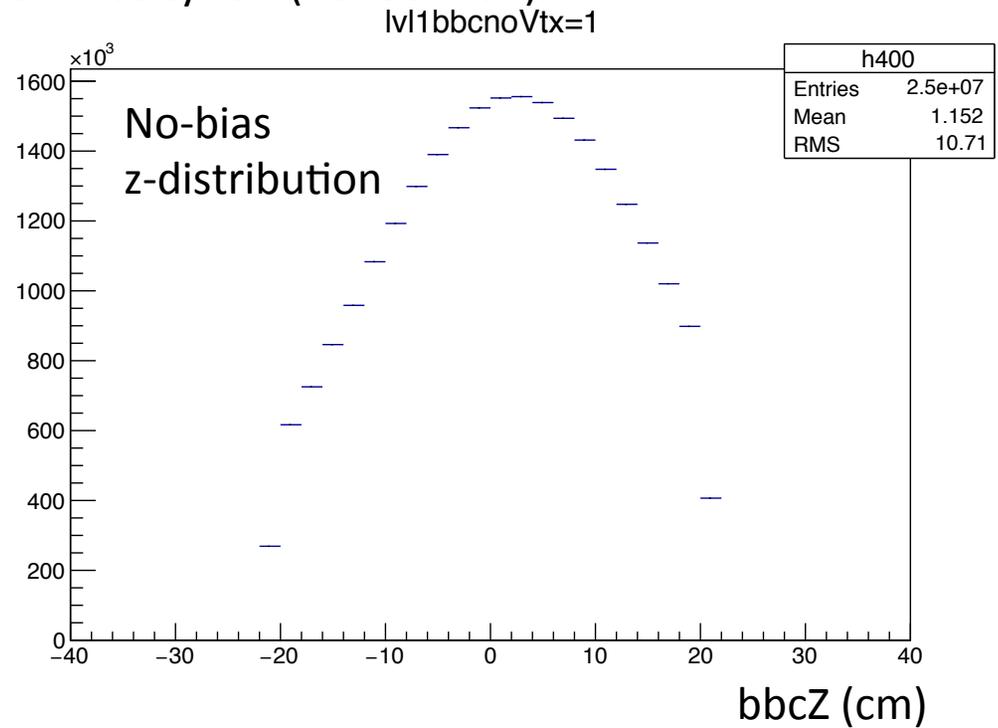
Effects of efficiency*acceptance

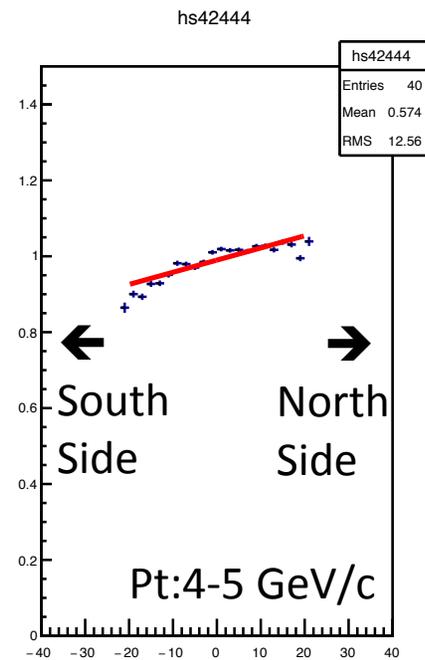
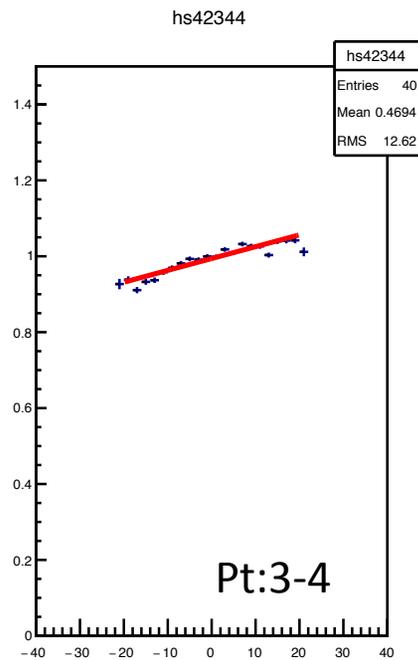
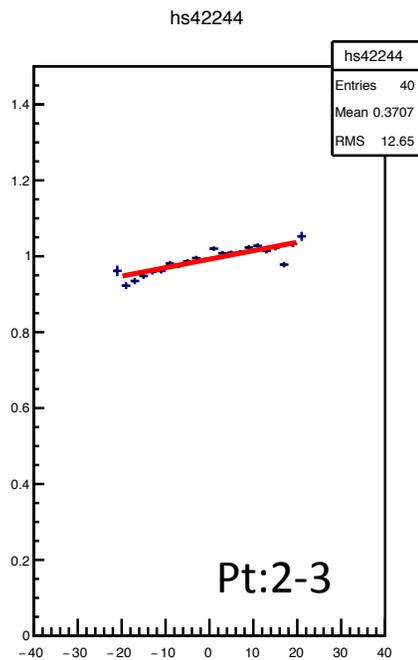
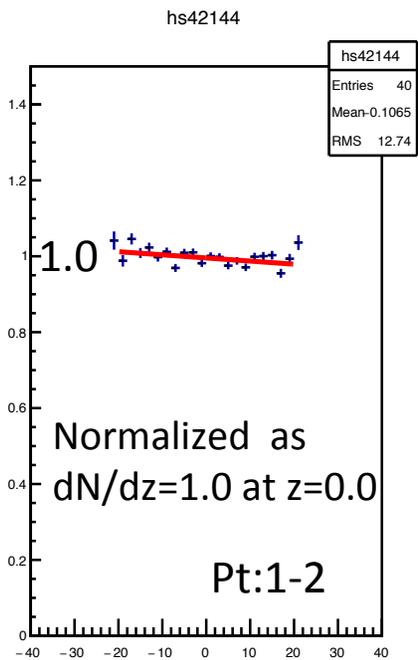
- Simulations of 25 millions single-muon events
- Uniform momentum distributions between $p\text{-init}=1.0\text{-}20.0$ GeV/c
- Random in solid angle, between pseudo-rapidity $1.2 < |\eta| < 2.4$
- “No-bias” bbcZ distribution following Run12pp510 data
- MuID-Efficiencies from a typical mid-luminosity run (Run367161)

Lastgap=4 muons, $p_{\text{tot}} > 4$ GeV/c
 Same geometry cuts as in data

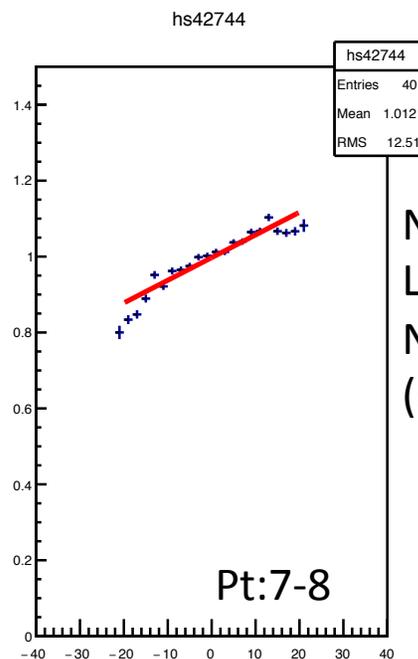
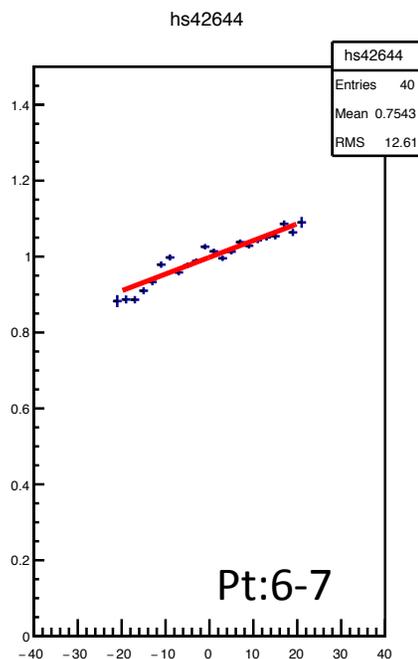
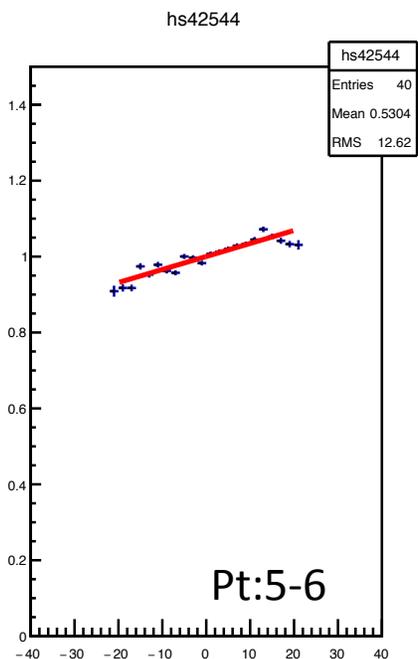
Accepted muons
 $dN(z)/dz = \text{-----}$
 No-bias bbcZ distribution

To set to the same scale, normalized to
 $dN(z=0)/dz = 1.0$ at $z = 0.0$ cm.





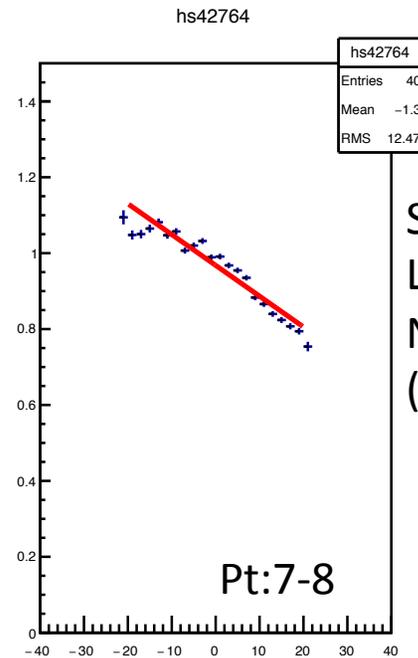
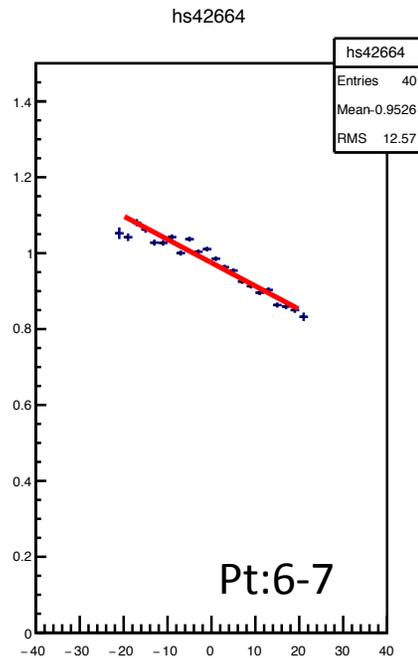
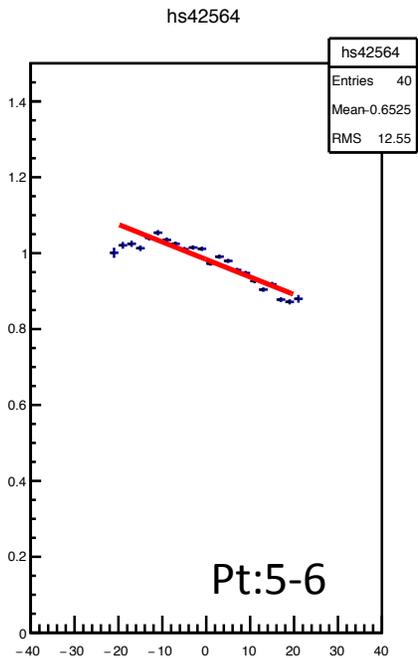
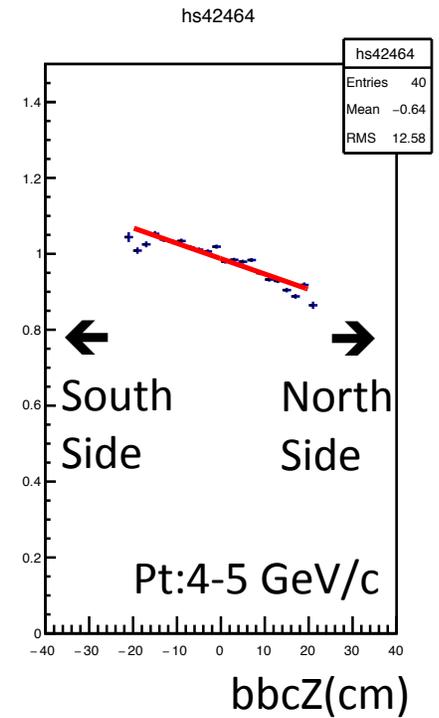
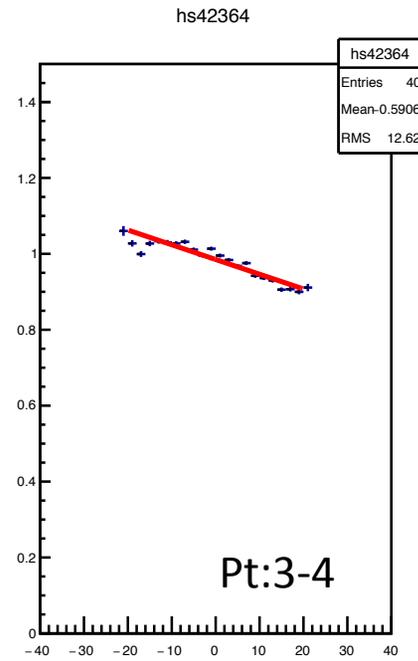
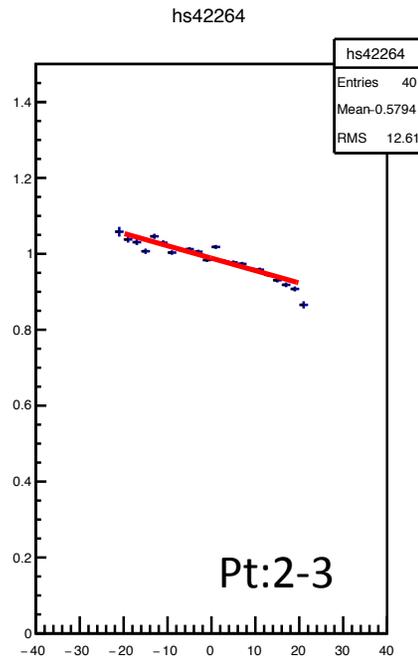
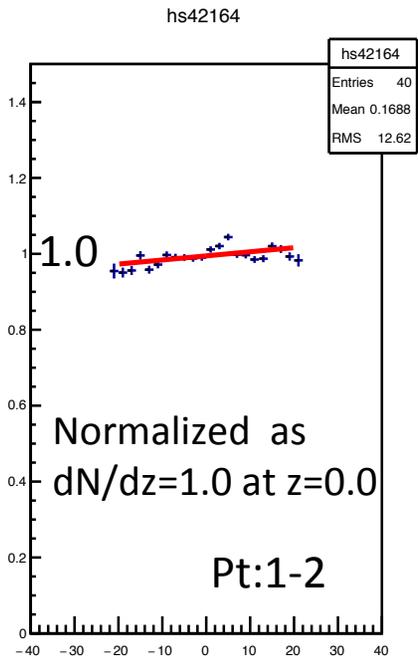
bbcZ(cm)



Single-muon simulations

NORTH''+''
 Lastgap=4 events
 Normalized dN/dz vs $bbcZ$
 (cm) for each Pt bin

Effects of
 Efficiency*Acceptance²³

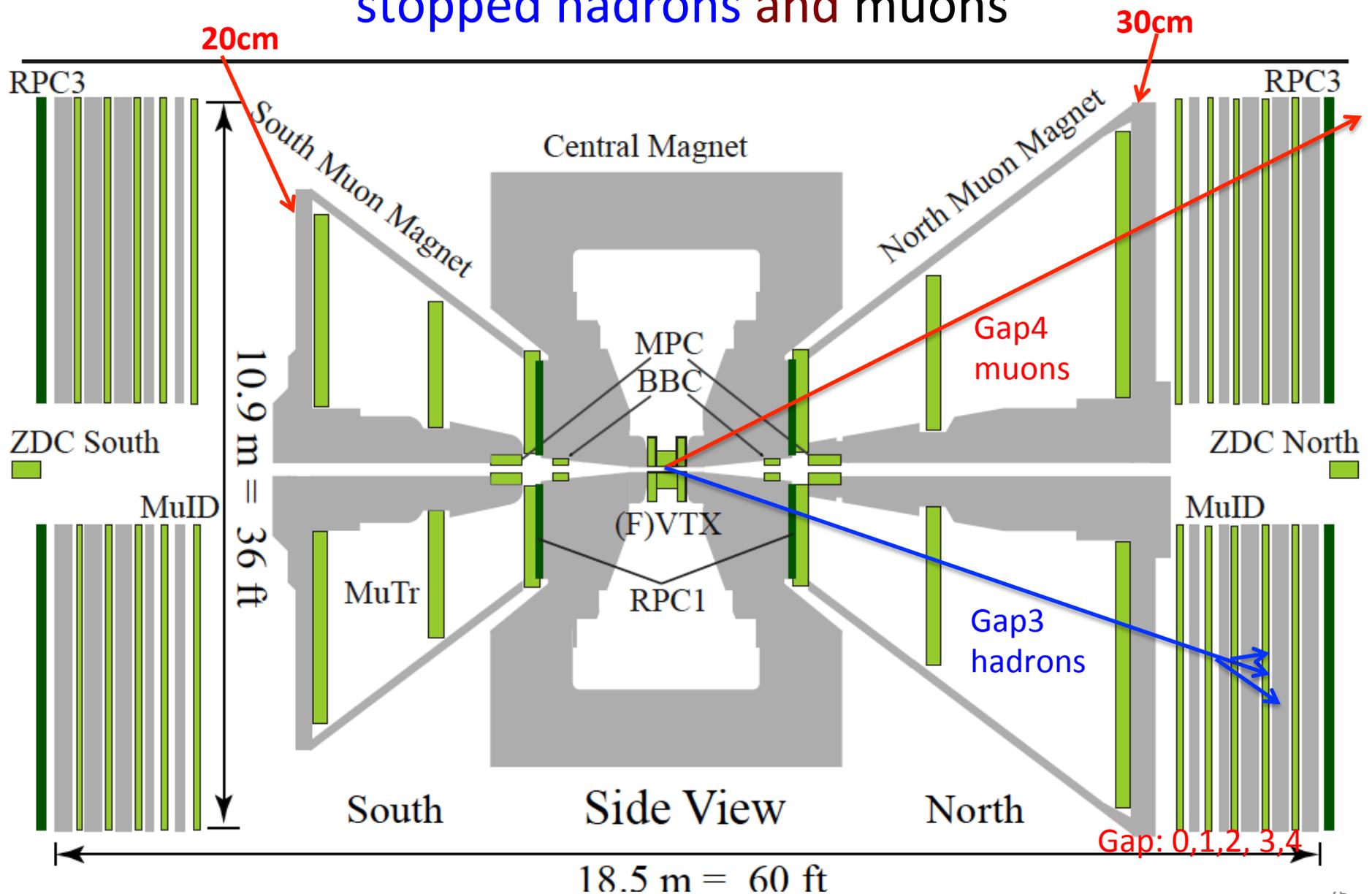


Single-muon simulations

SOUTH''+''
 Lastgap=4 events
 Normalized dN/dz vs $bbcZ$
 (cm) for each Pt bin

Effects of
 Efficiency*Acceptance₂₄

Reconstructed “Muons” tagged at various Gaps stopped hadrons and muons

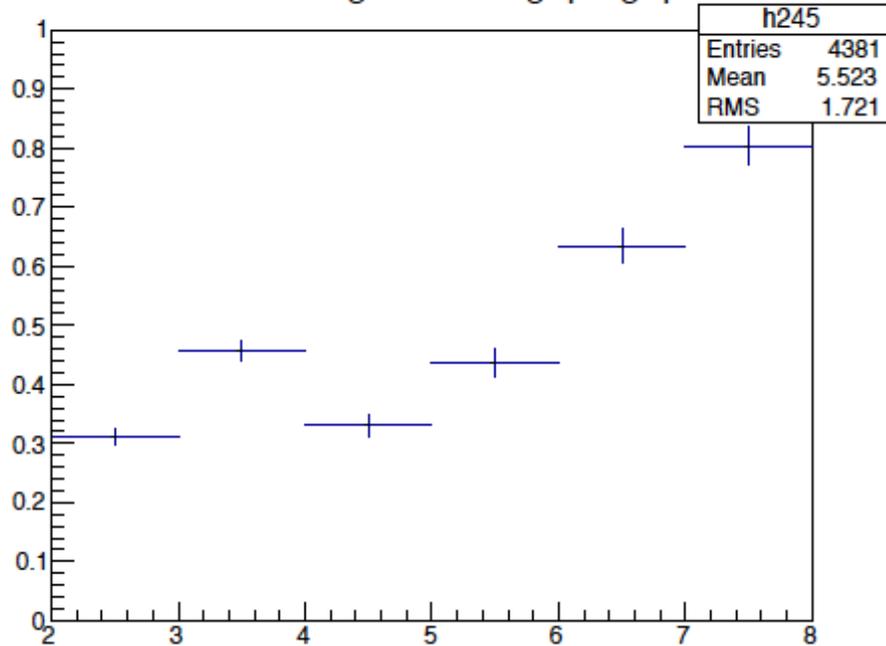


Simulation Results-II

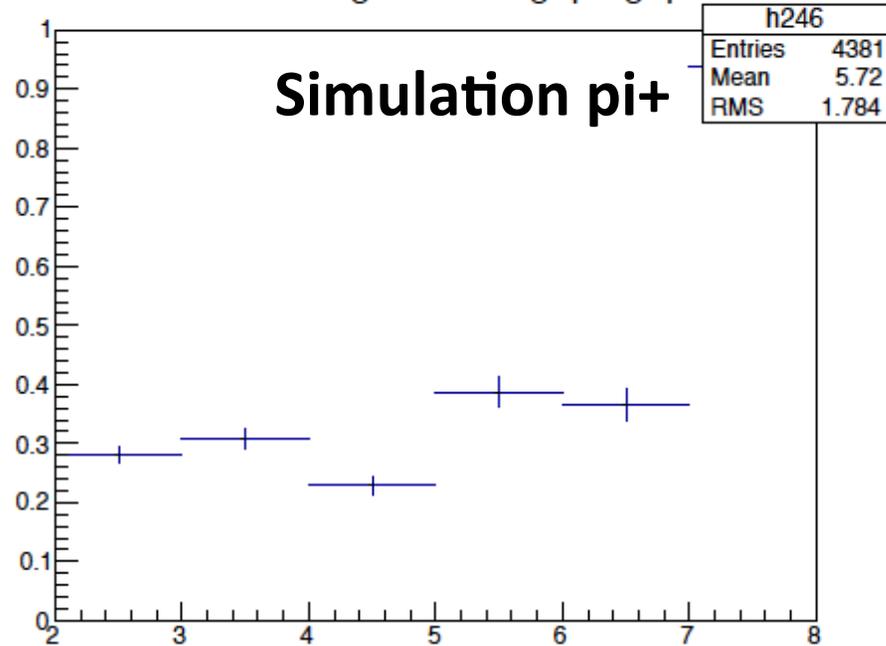
Single-Hadron Simulations

- 25 million events each for μ^+ , μ^- , π^+ , π^- , k^+ , k^- (took ~ 3 weeks on rcf).
- Still, very limited statistics (see plots)
- Another simulation effort (M. Snowball) has been carried out on Open Science Grid, over three months. Output has become partially available. A very large disk space ($\sim 1\text{TB}$) is needed to store and process these simulation results.

North Charge 1 ratio gap2/gap4

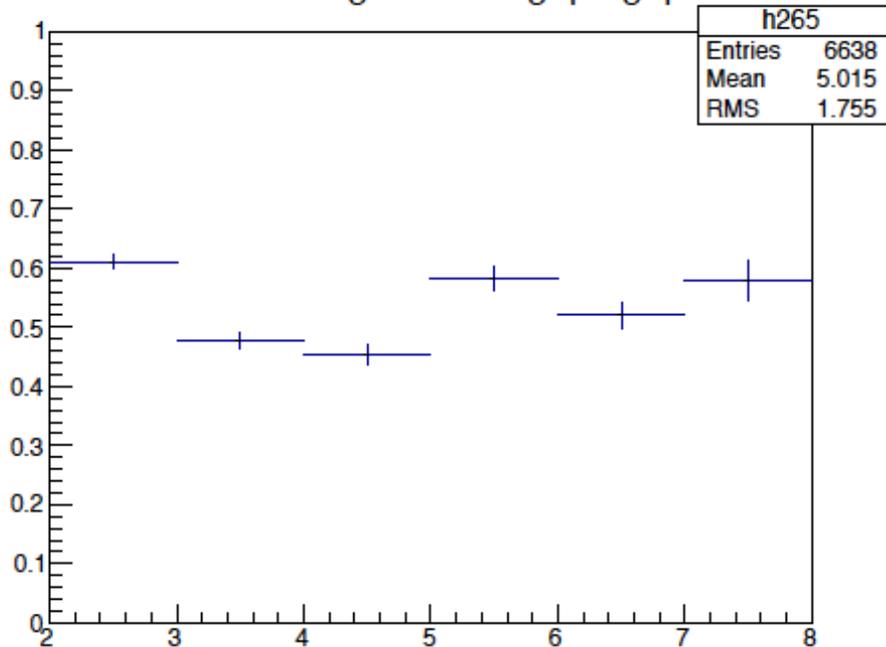


North Charge 1 ratio gap3/gap4

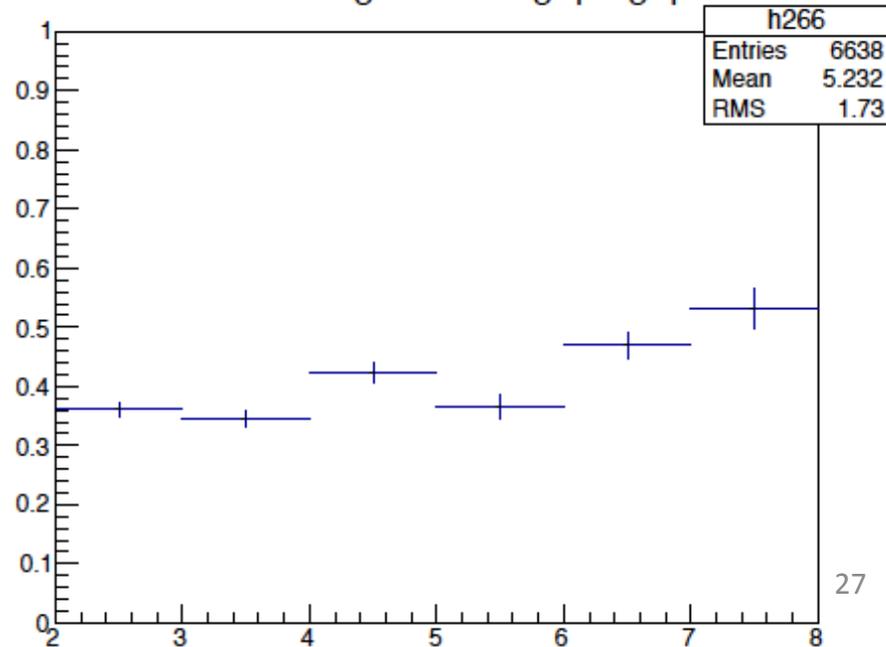


Pt (GeV/c)

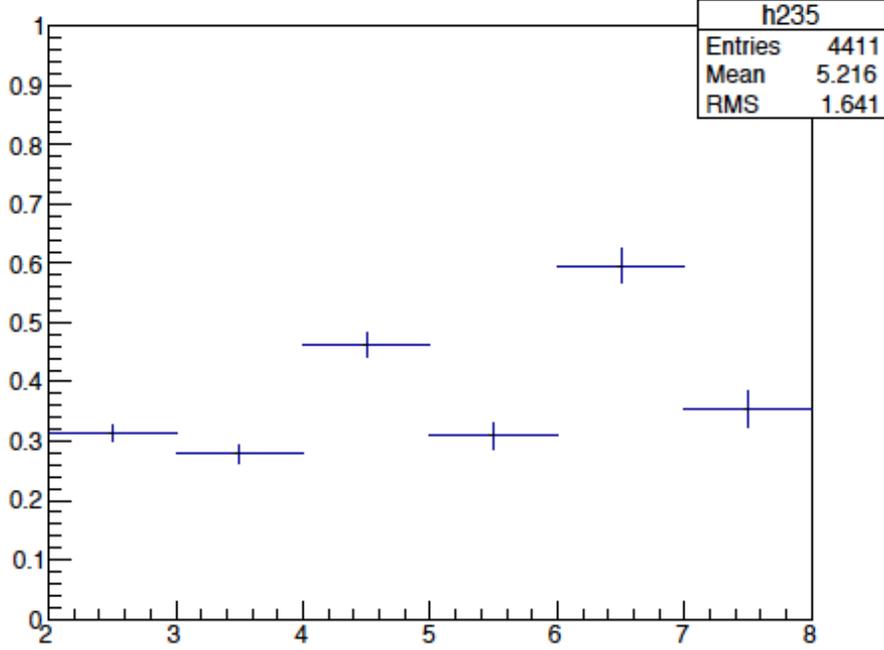
South Charge 1 ratio gap2/gap4



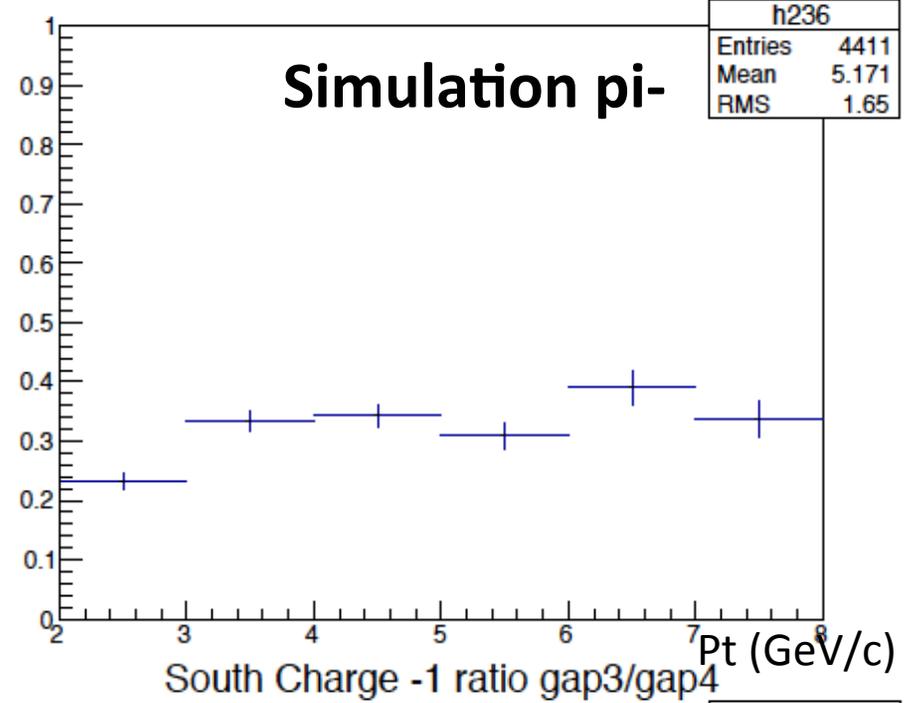
South Charge 1 ratio gap3/gap4



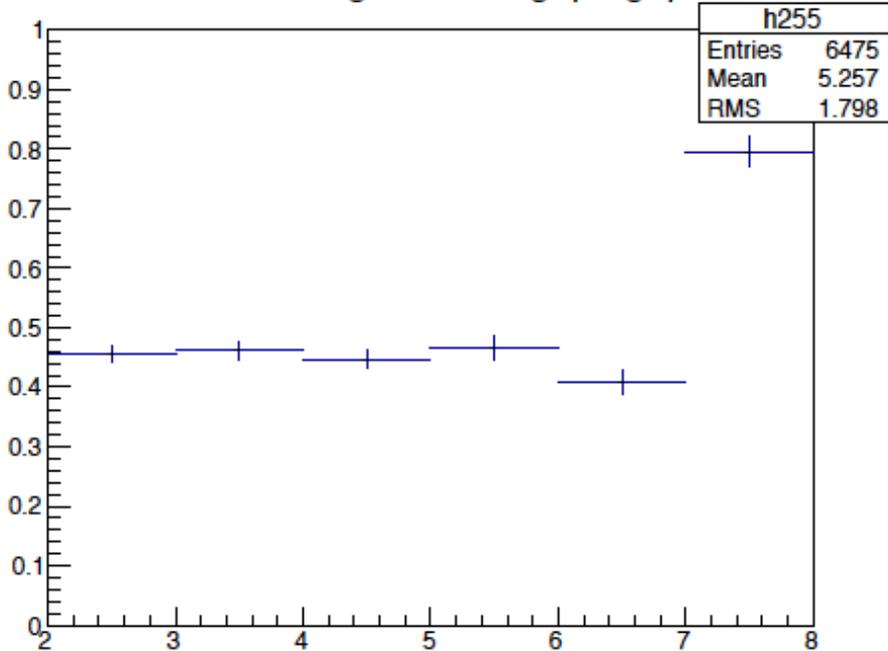
North Charge -1 ratio gap2/gap4



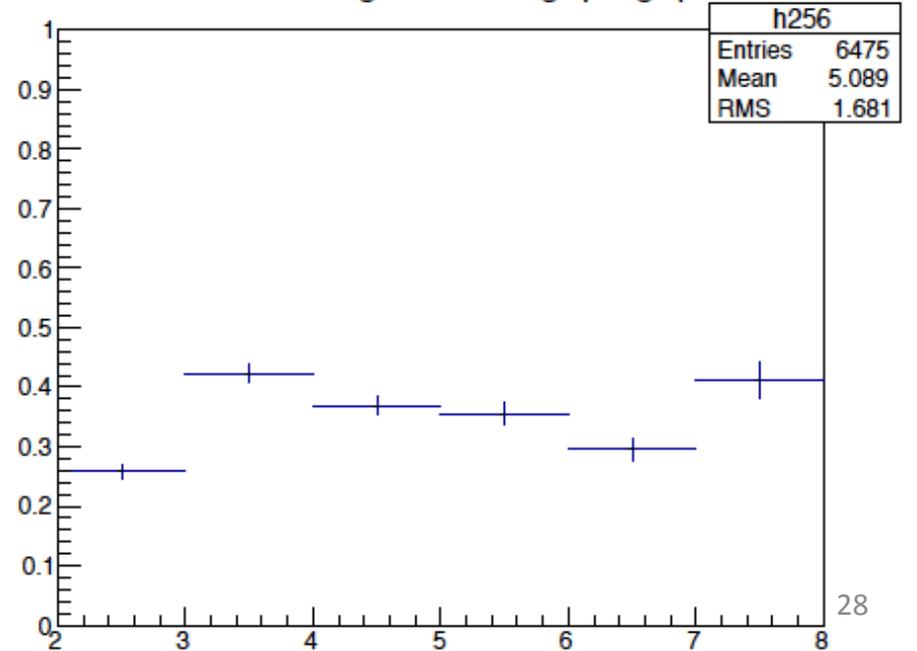
North Charge -1 ratio gap3/gap4



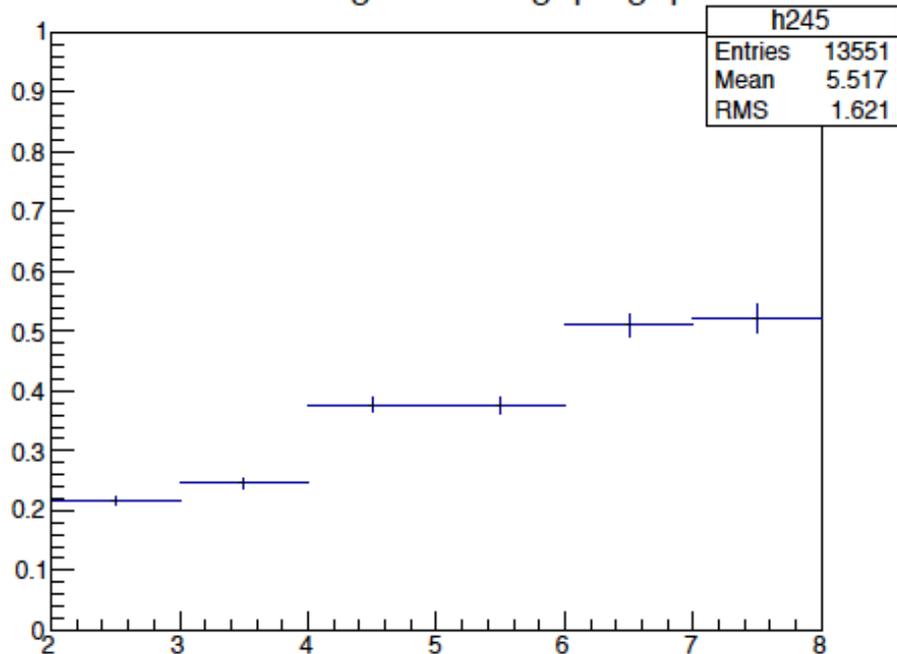
South Charge -1 ratio gap2/gap4



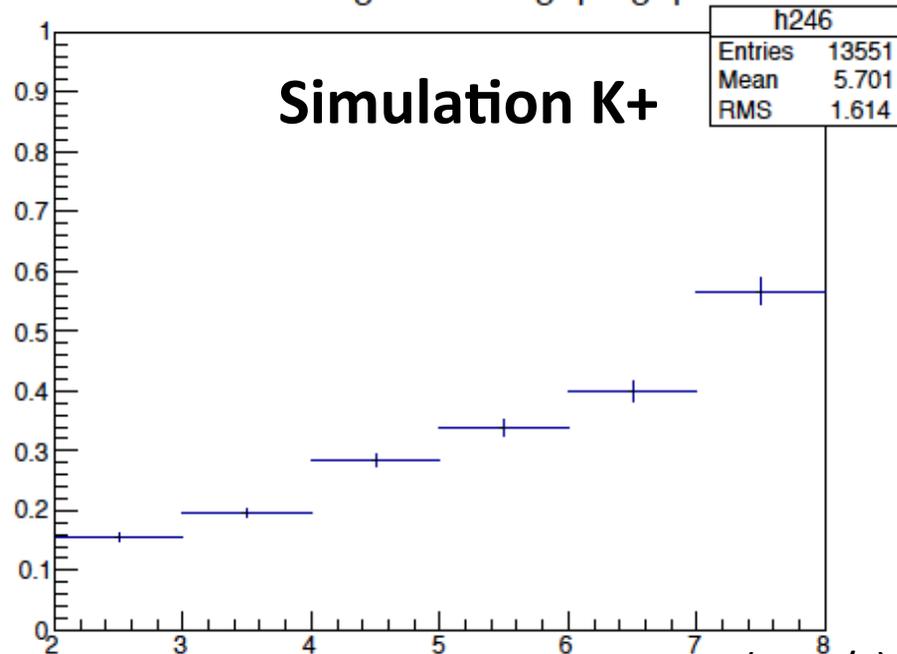
South Charge -1 ratio gap3/gap4



North Charge 1 ratio gap2/gap4

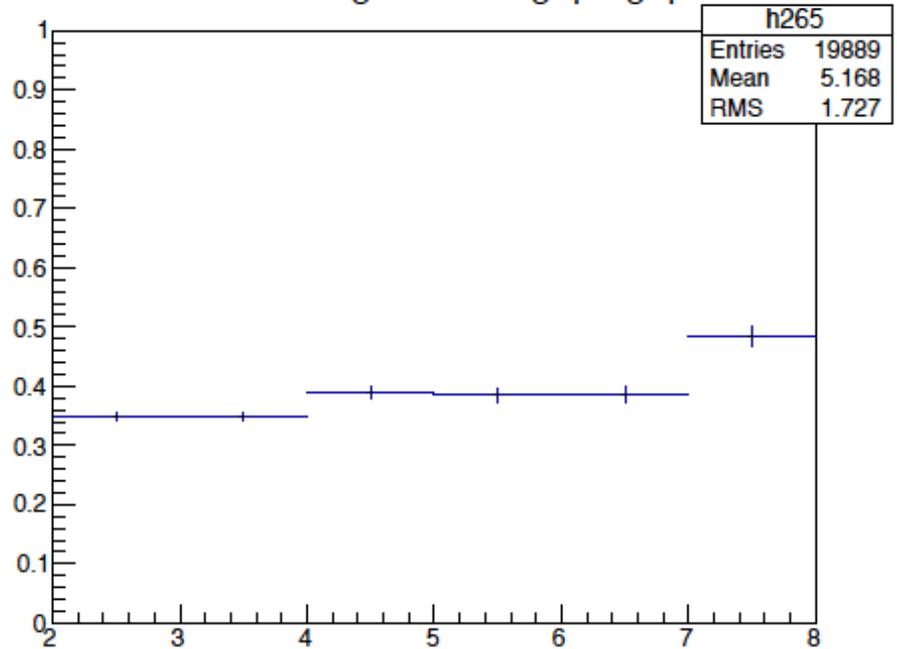


North Charge 1 ratio gap3/gap4

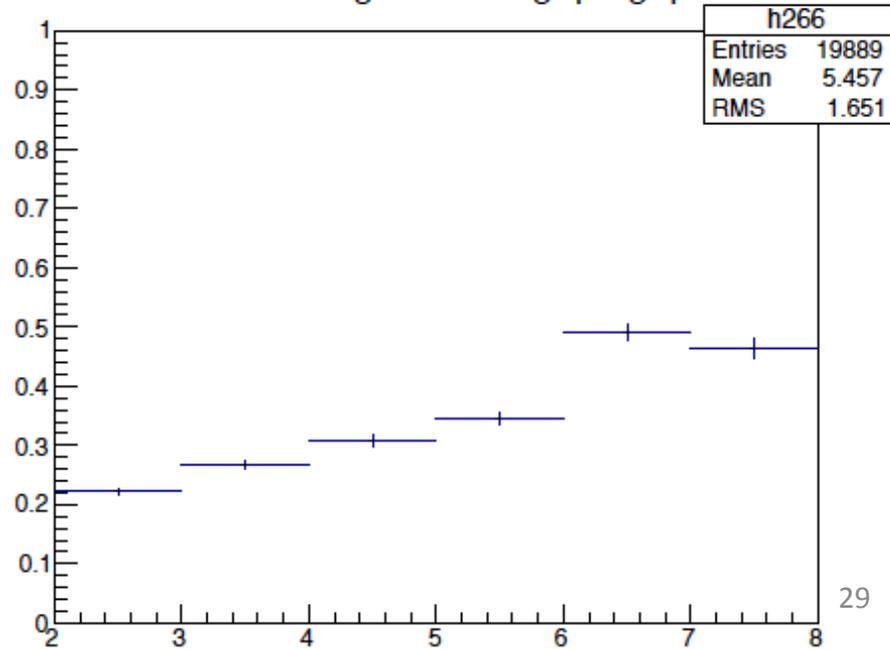


Pt (GeV/c)

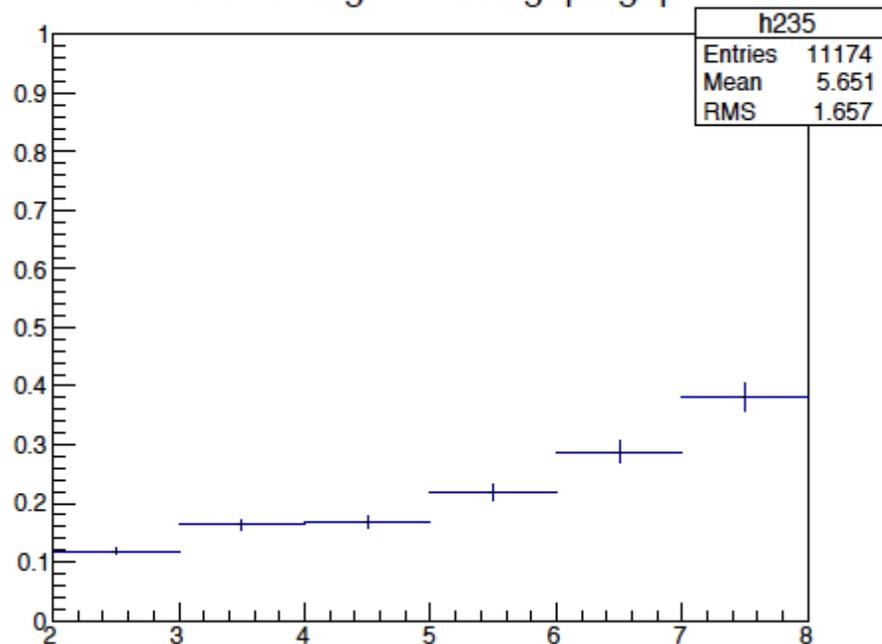
South Charge 1 ratio gap2/gap4



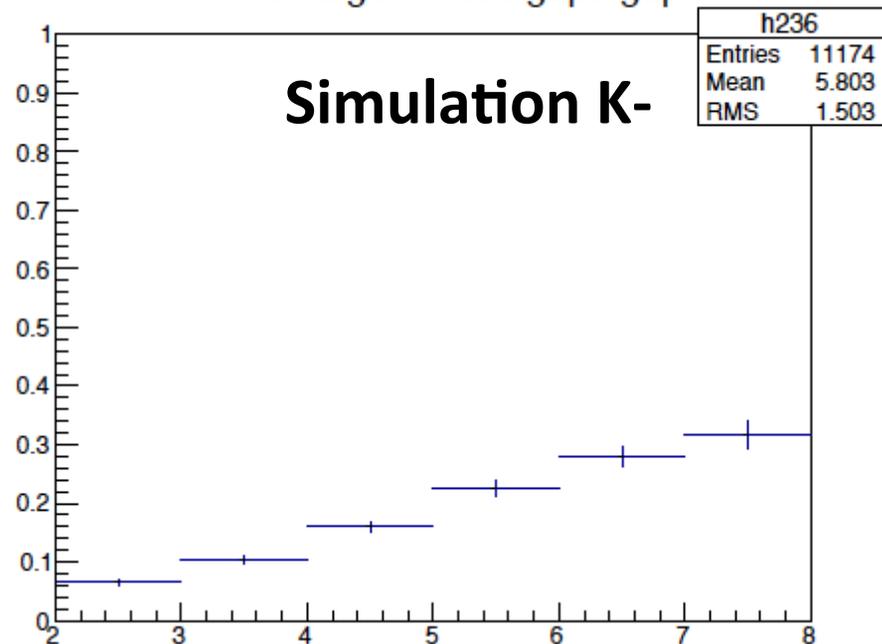
South Charge 1 ratio gap3/gap4



North Charge -1 ratio gap2/gap4

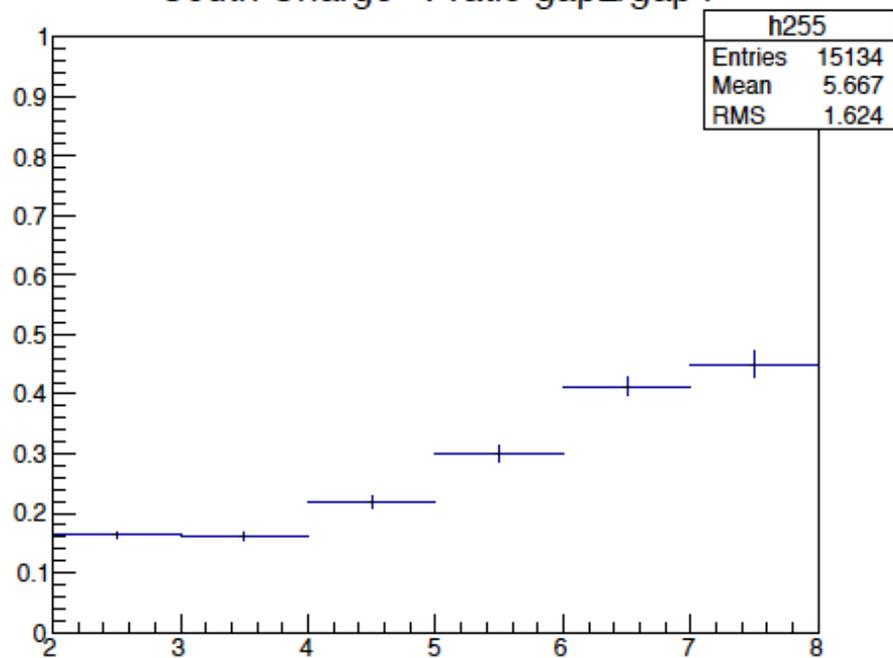


North Charge -1 ratio gap3/gap4

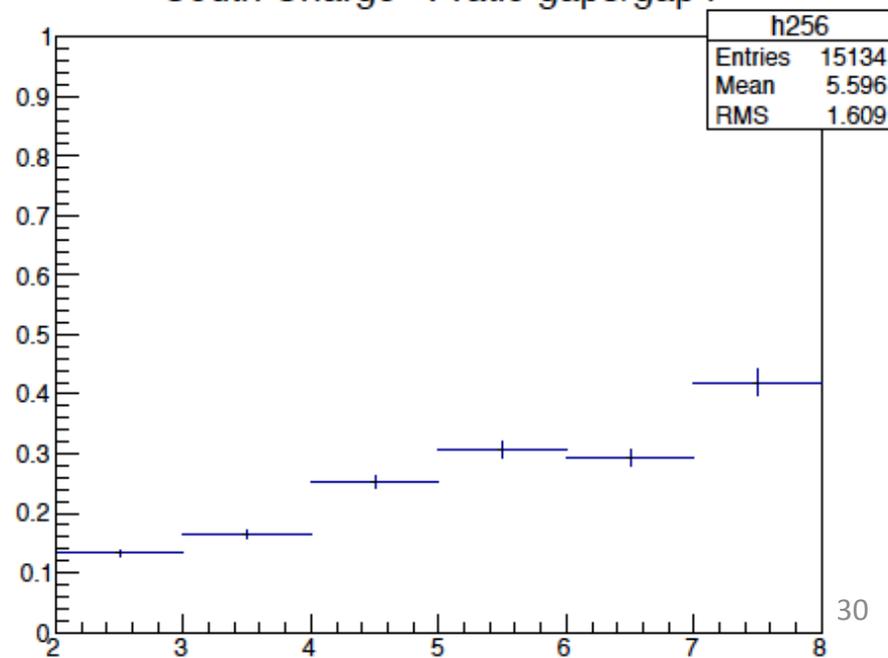


Pt (GeV/c)

South Charge -1 ratio gap2/gap4



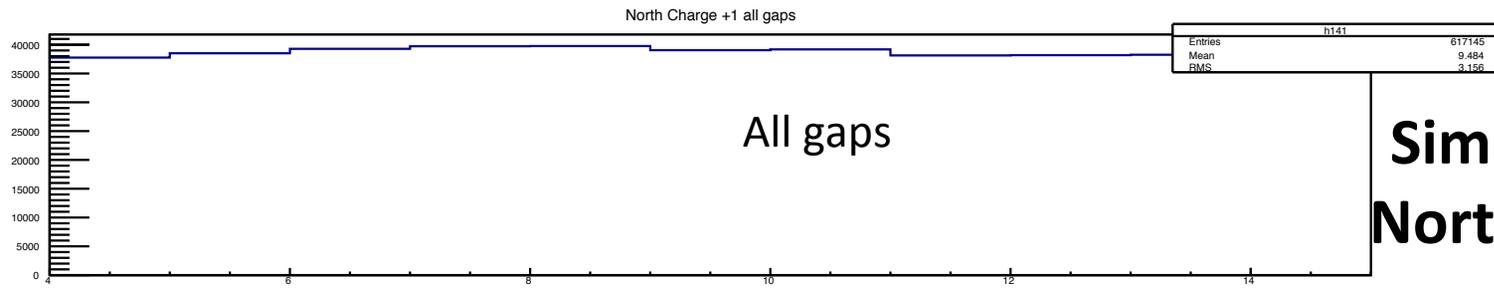
South Charge -1 ratio gap3/gap4



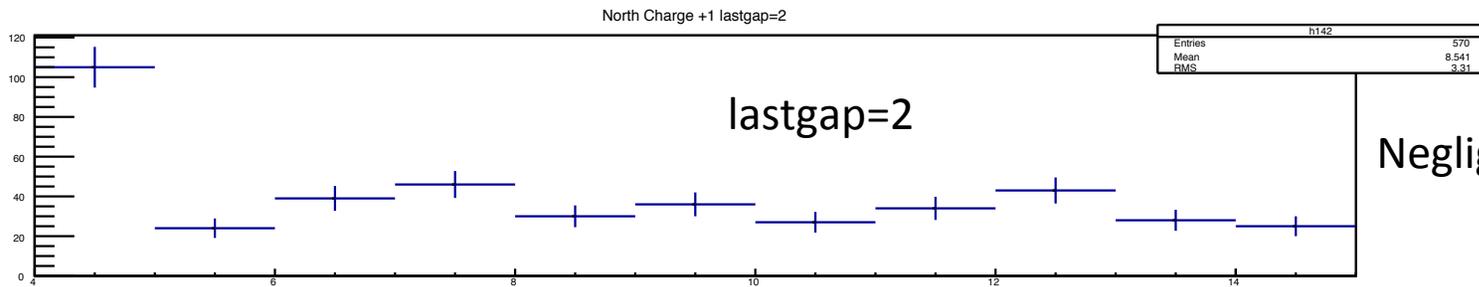
Compromises

Treat K/pi ratio as known inputs, to reduce the overall number of unknowns.
From Pythia8, or from an initial guess based on 200 GeV measurements.

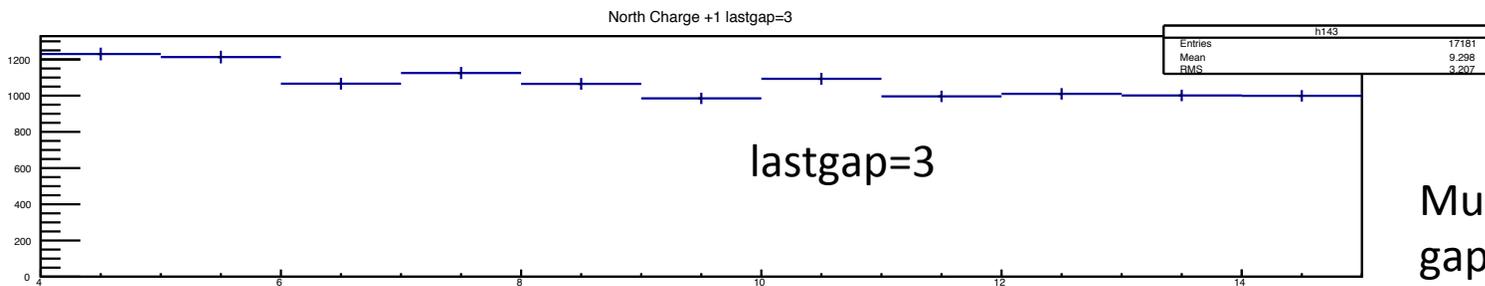
Not to trust lastgap=2 events, due to a “lower quality” on MUID roads.



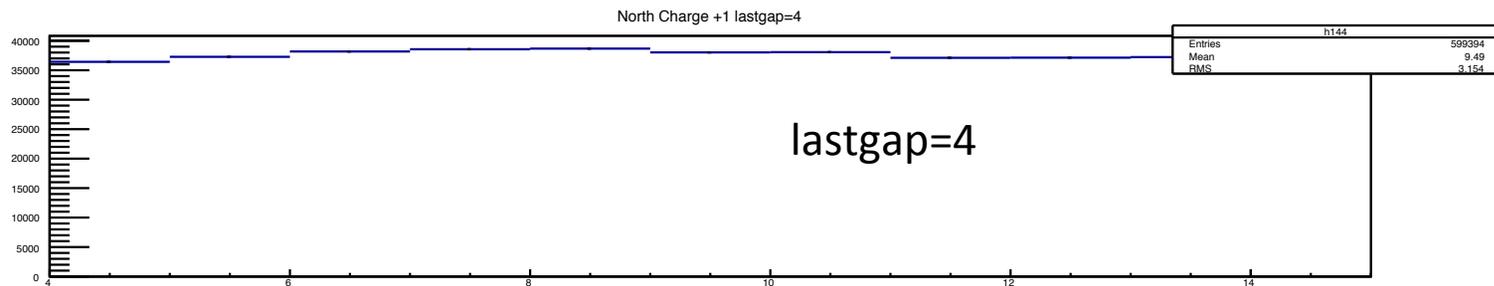
**Simulation mu+
North charge= +1**



Negligible gap2 events

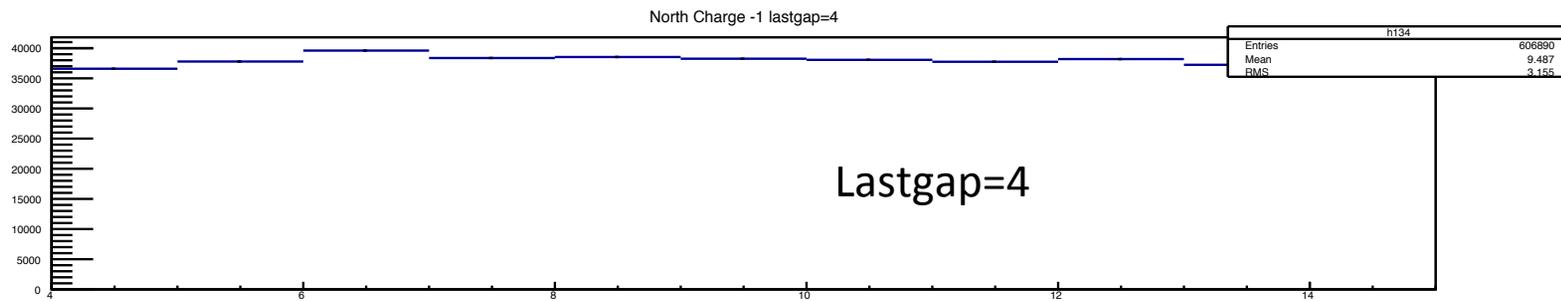
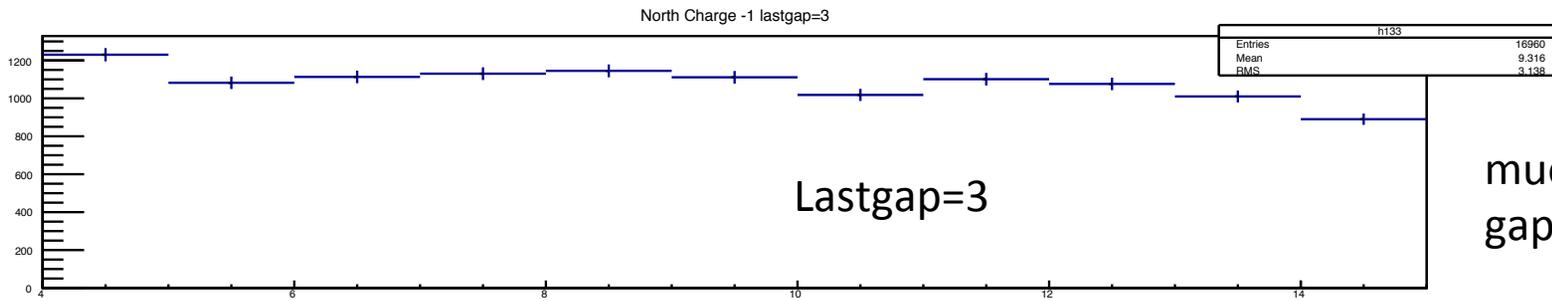
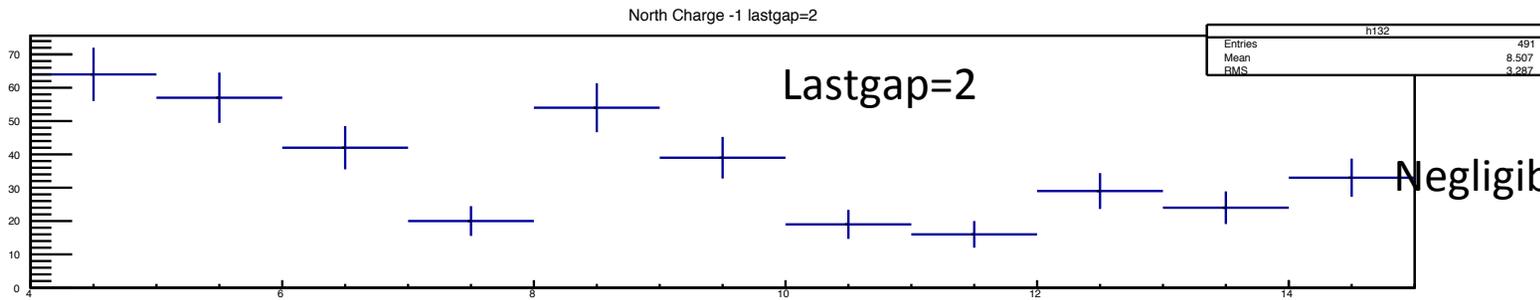
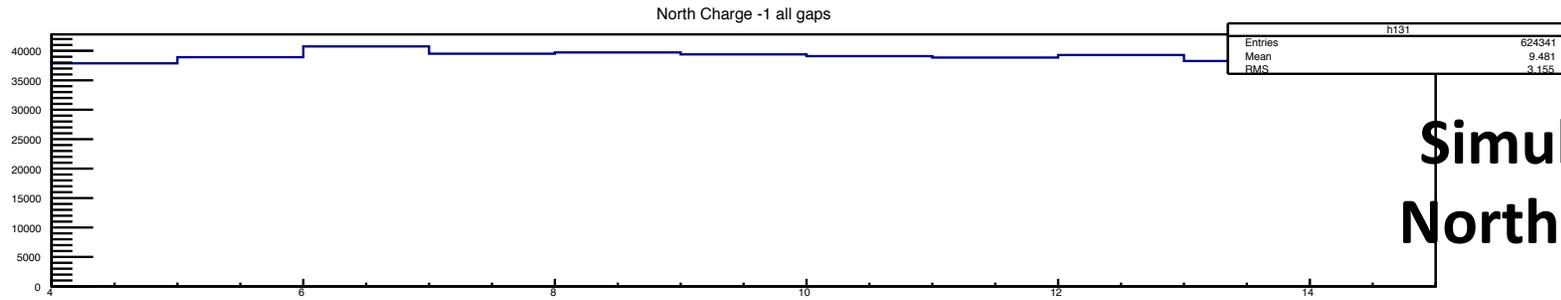


Muon+ North
gap3/gap4=2.8%



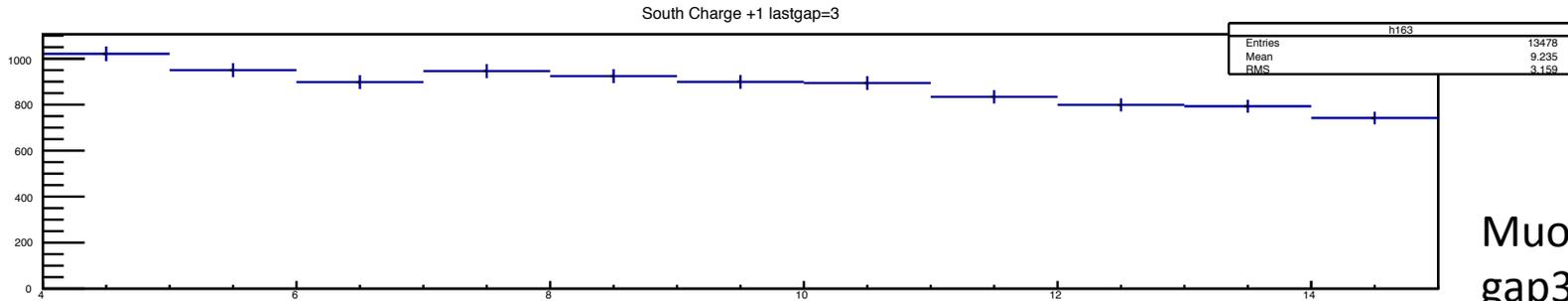
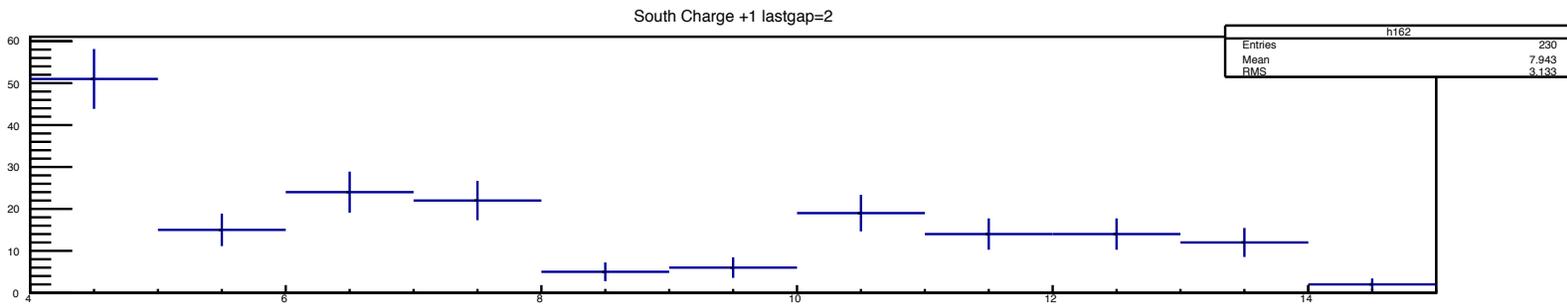
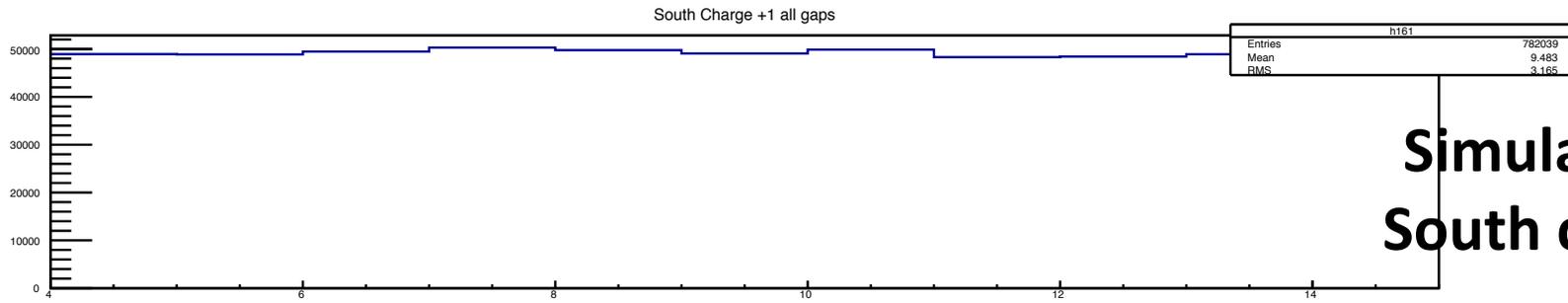
Ptot (GeV/c)

Simulation mu- North charge= -1

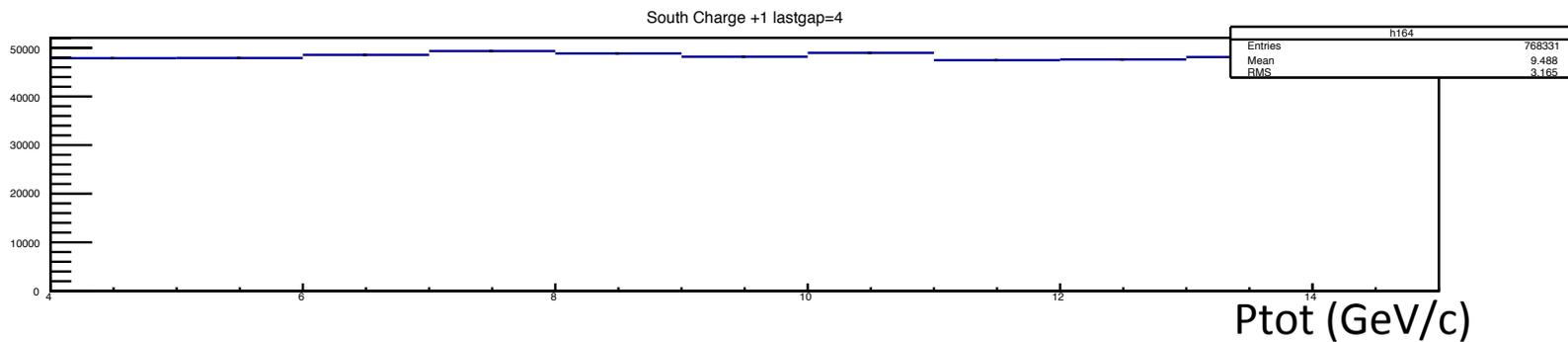


Ptot (GeV/c)

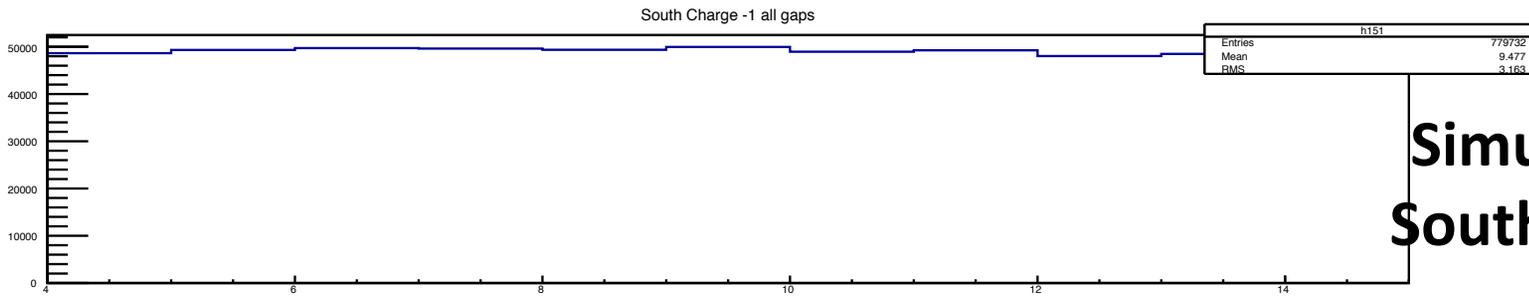
Simulation mu+ South charge= +1



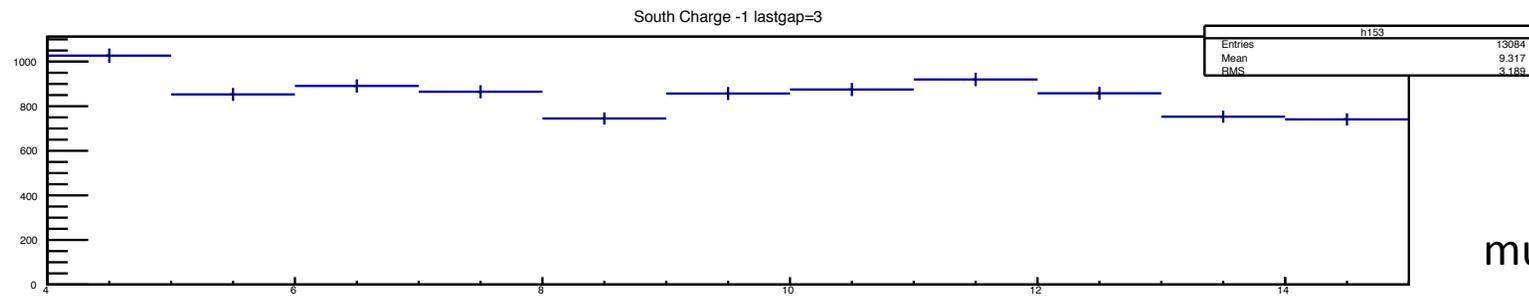
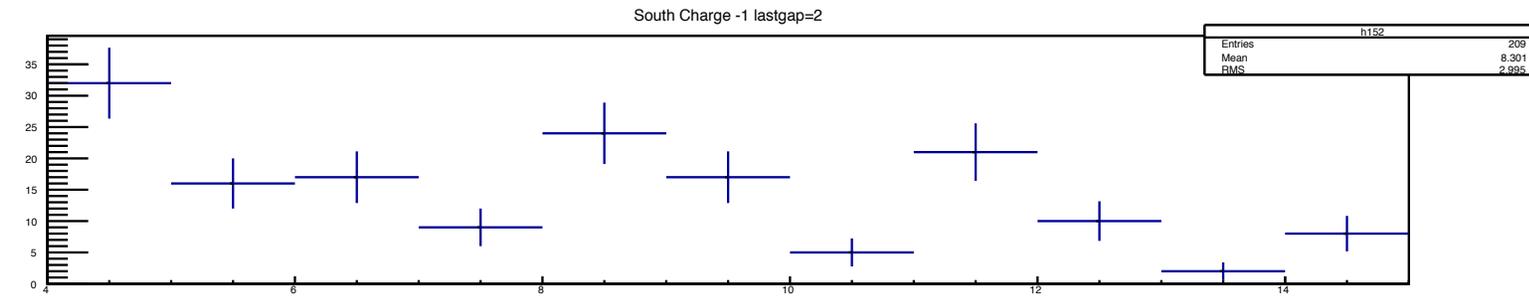
Muon+ South
gap3/gap4=1.7%



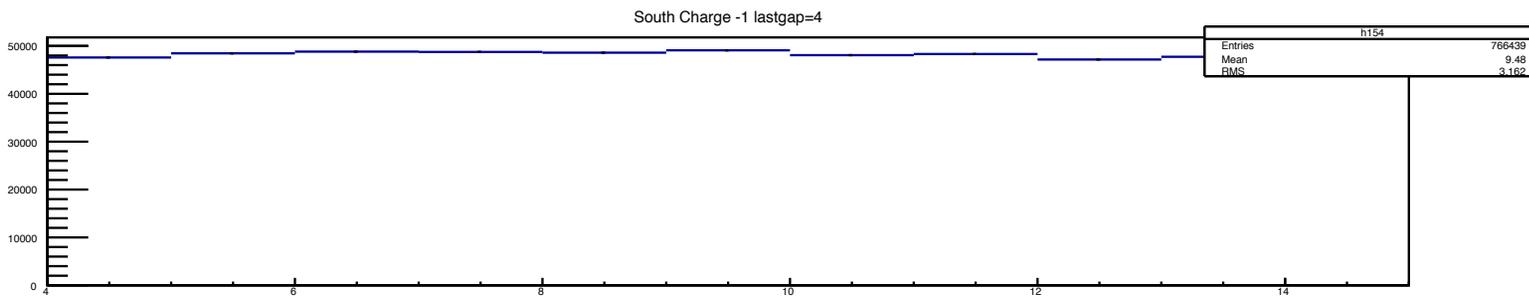
Ptot (GeV/c)



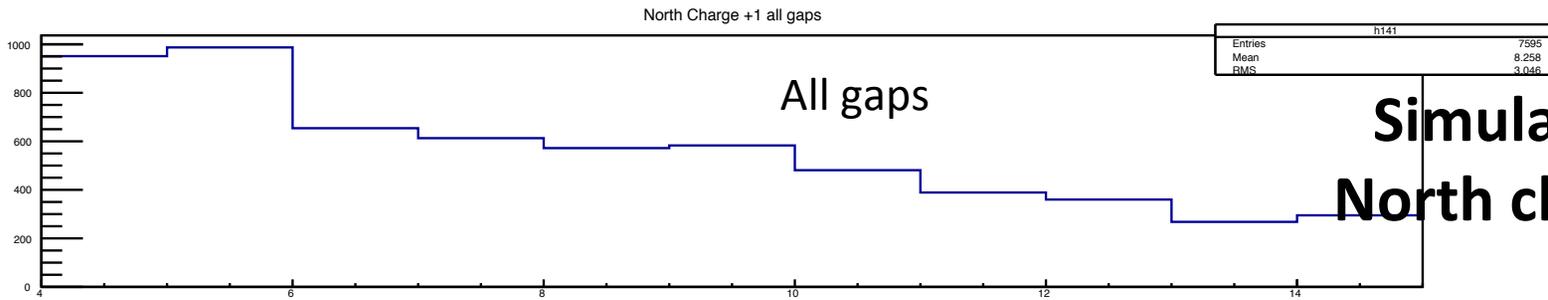
**Simulation mu-
South charge= -1**



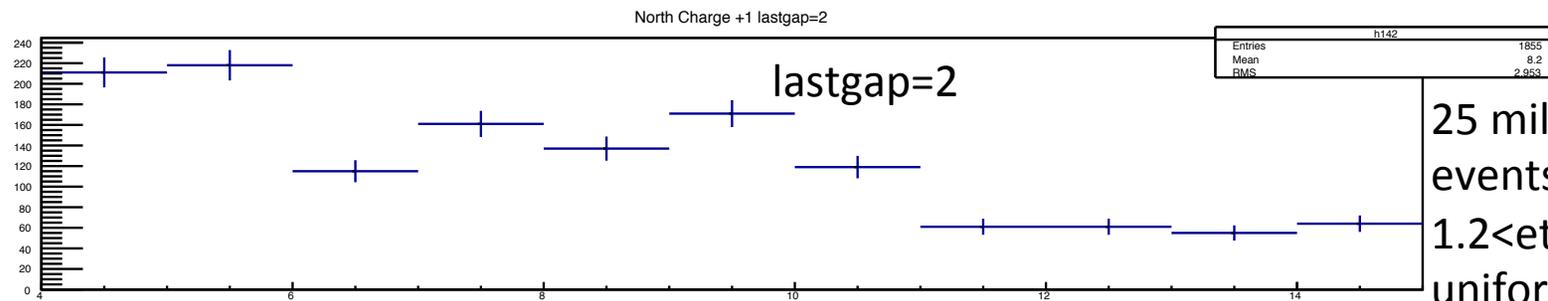
**muon- South
gap3/gap4=1.7%**



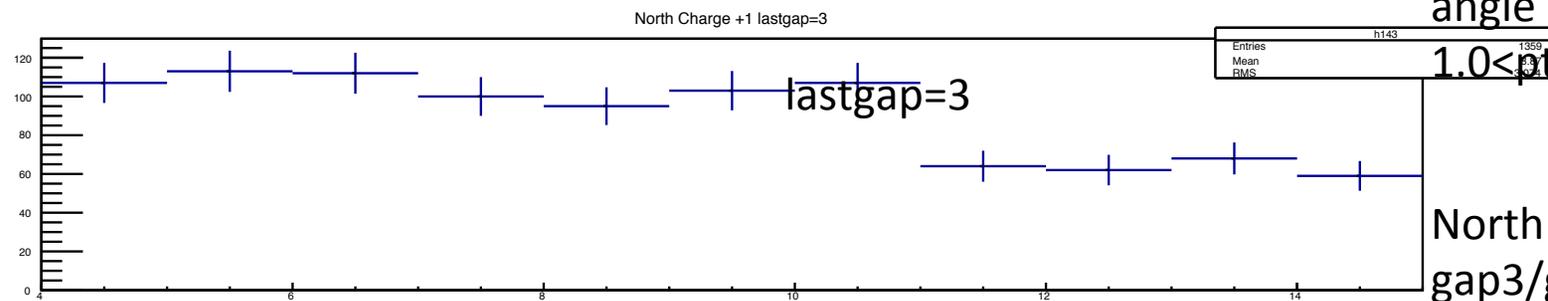
Ptot (GeV/c)



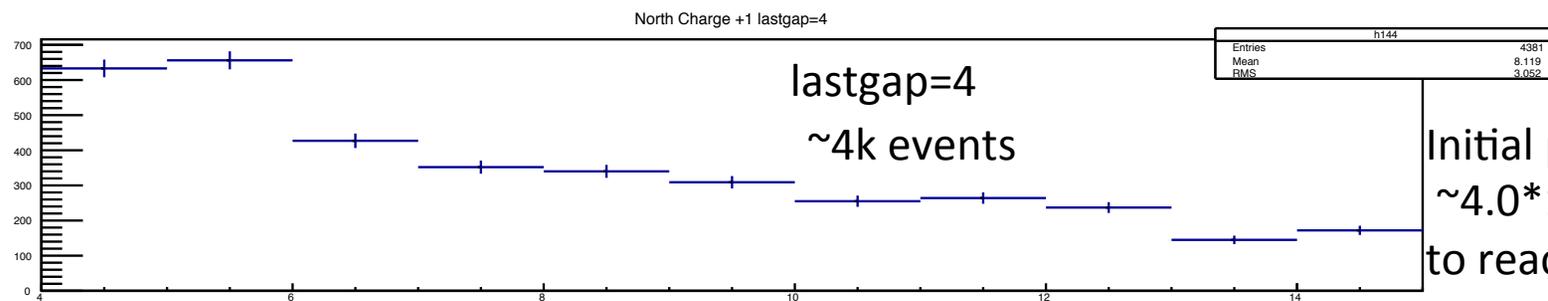
Simulation pi+
North charge= +1



25 million initial events
1.2 < eta < 2.4
uniform in solid angle

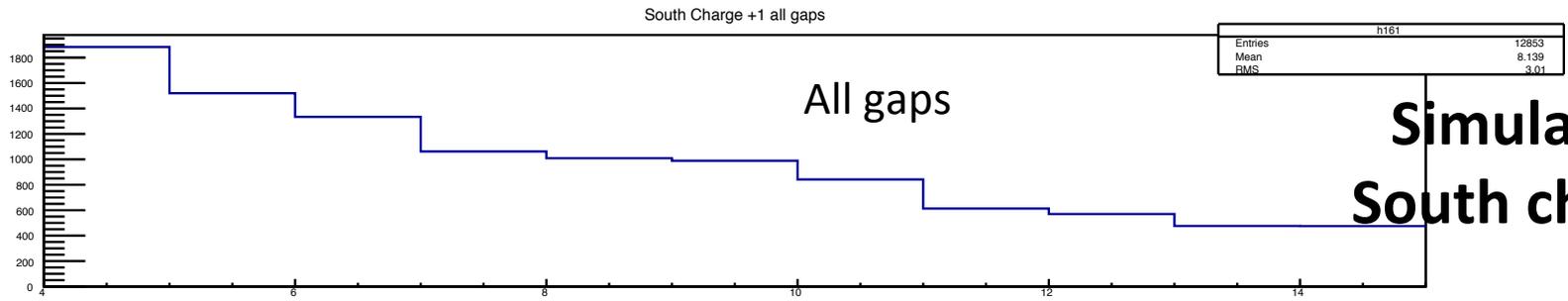


1.0 < Ptot < 20 GeV/c
North initial pi+
gap3/gap4: ~ 28%

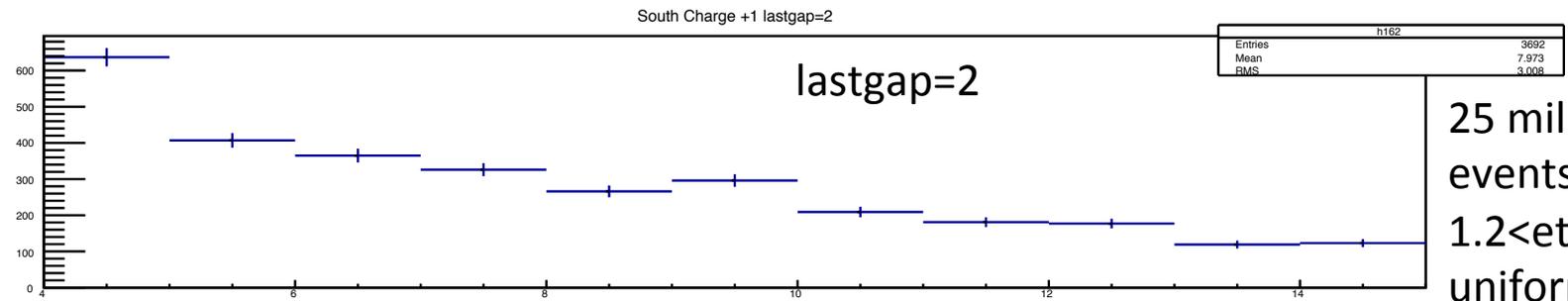


Initial pi+ events:
~4.0 * 10^-4 prop.
to reach gap4

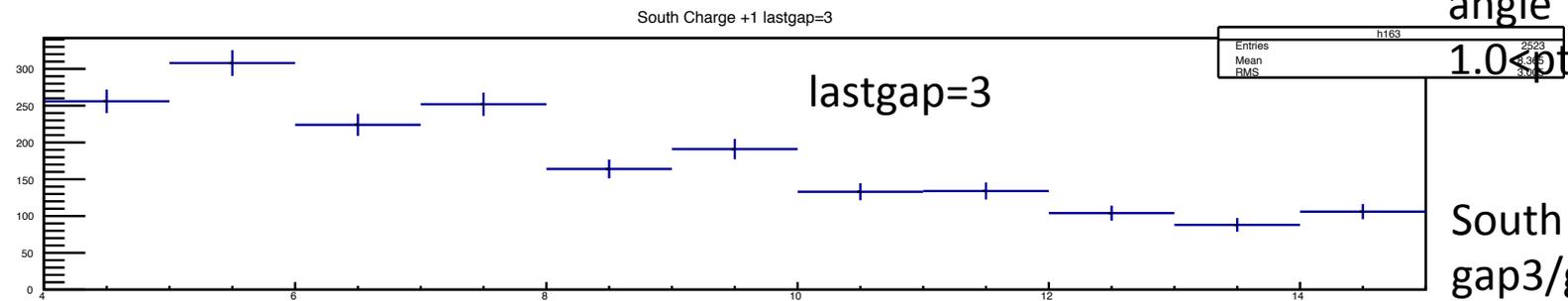
Ptot (GeV/c)



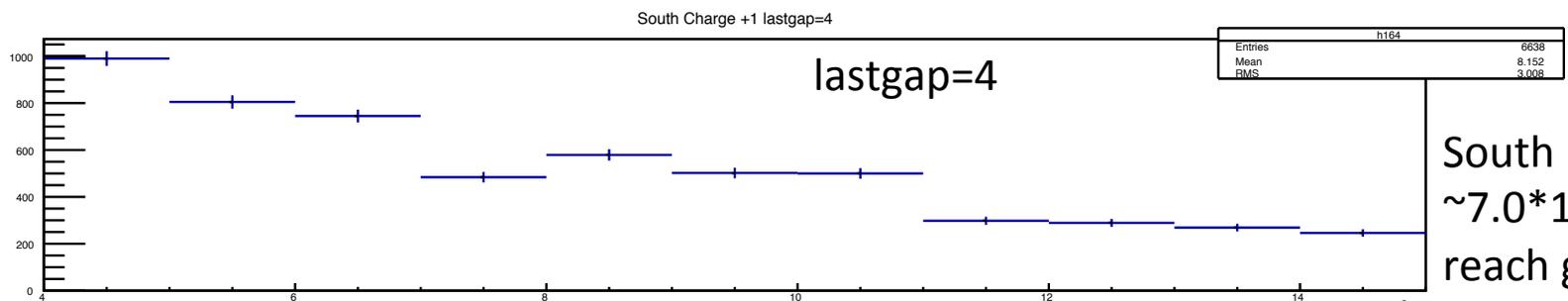
Simulation pi+
South charge= +1



25 million initial events
1.2 η <math>< 2.2</math>
uniform in solid angle

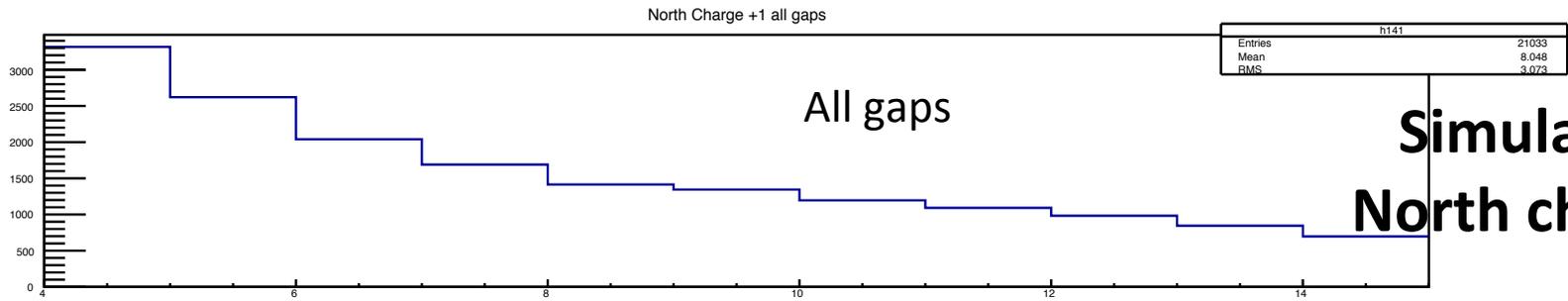


1.0 ϕ <math>< 2\pi</math>
South initial pi+
gap3/gap4: ~ 40%

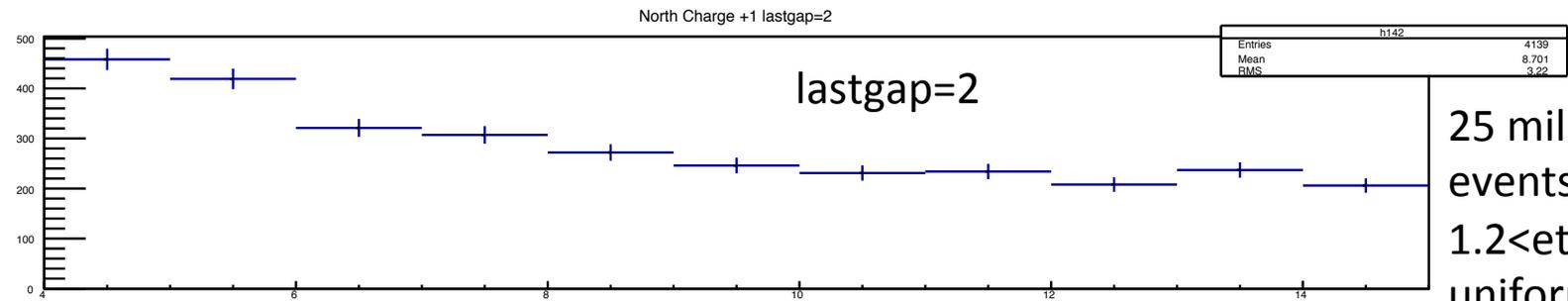


South Initial pi+:
~7.0*10⁻⁴ prop. to reach gap4

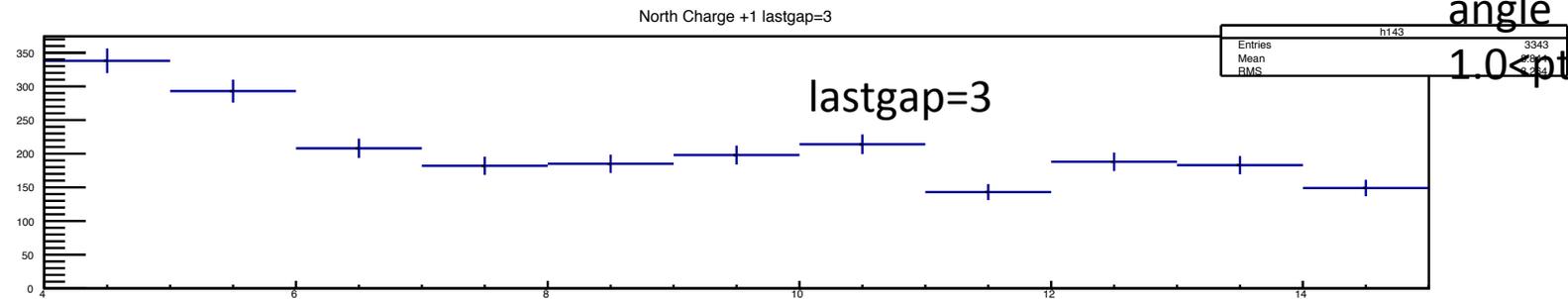
Ptot (GeV/c)



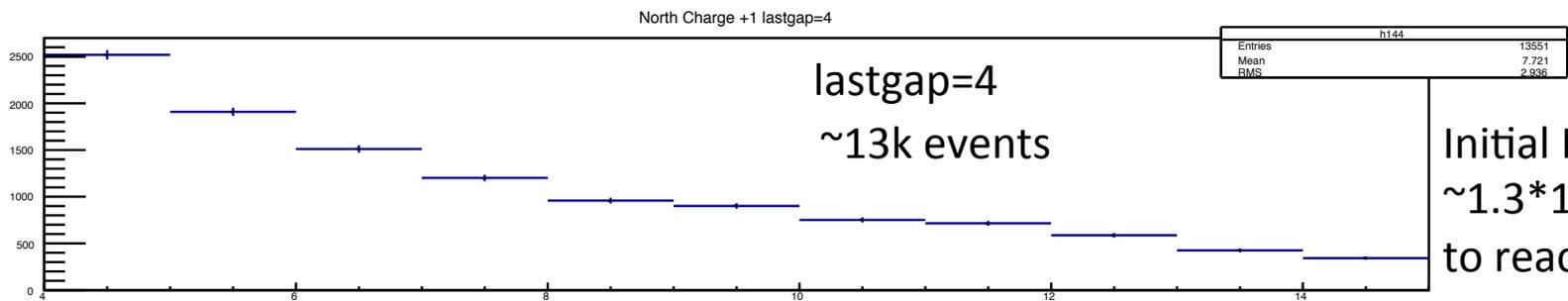
Simulation K+
North charge= +1



25 million initial events
1.2 η <math>< 2.2</math>
uniform in solid angle



1.0 ϕ <math>< 20</math> GeV/c

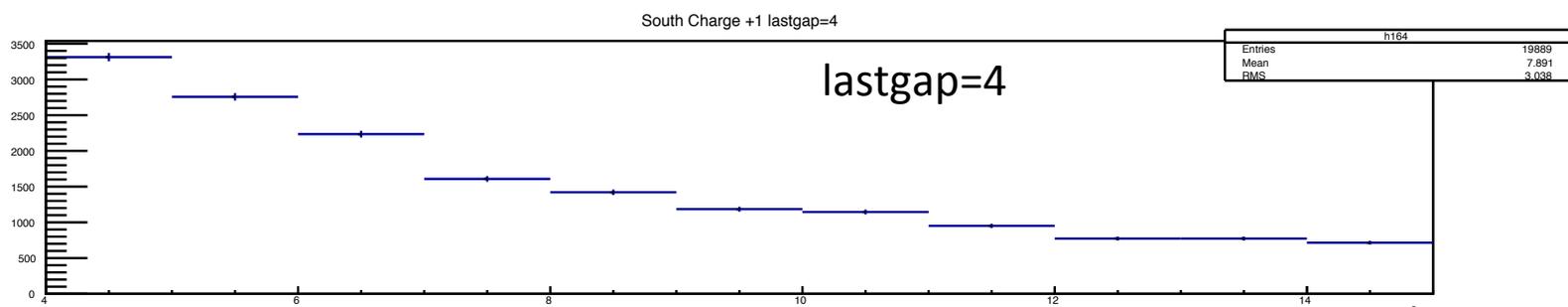
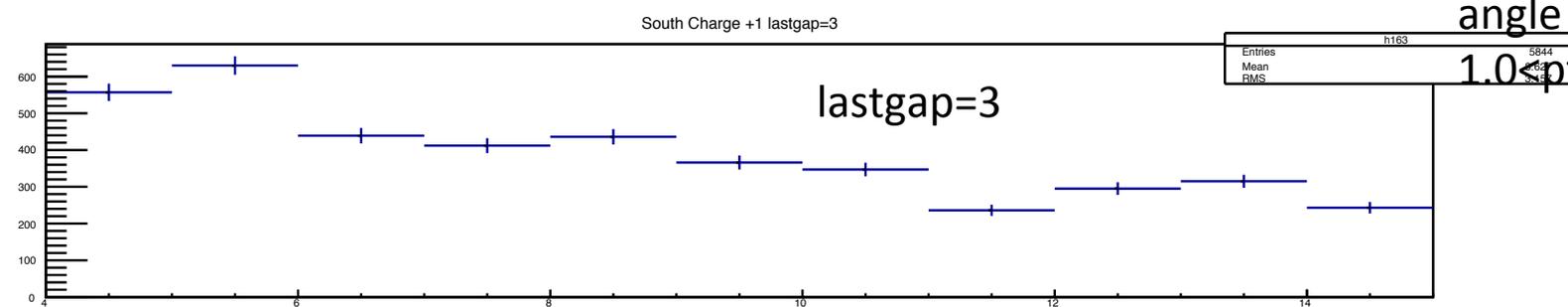
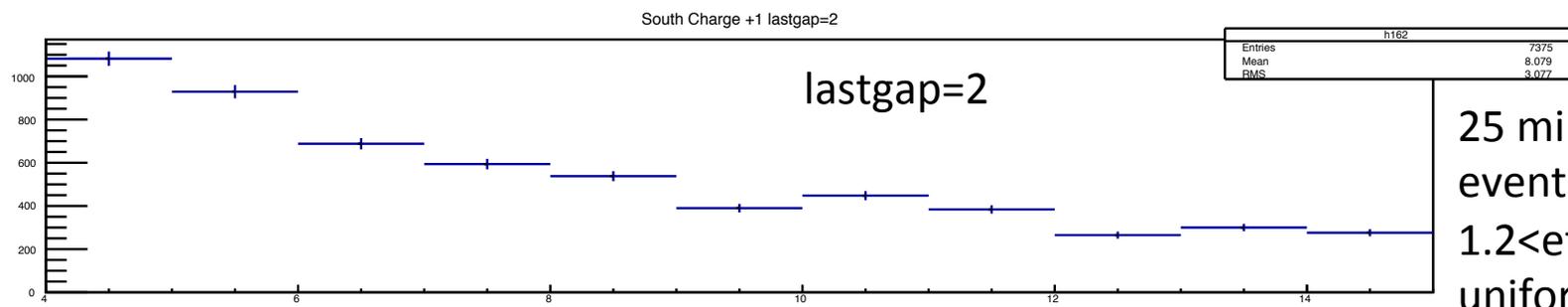
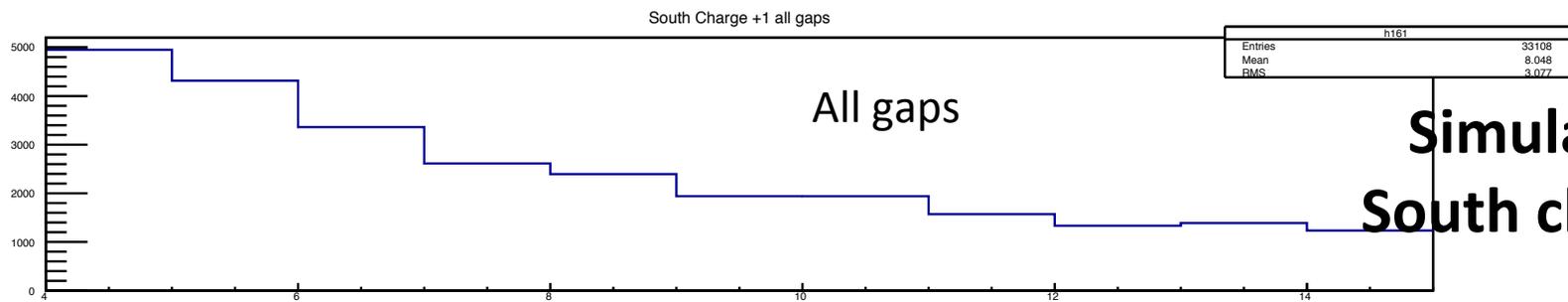


lastgap=4
~13k events

Initial K+ events:
~1.3 * 10⁻³ prop.
to reach gap4

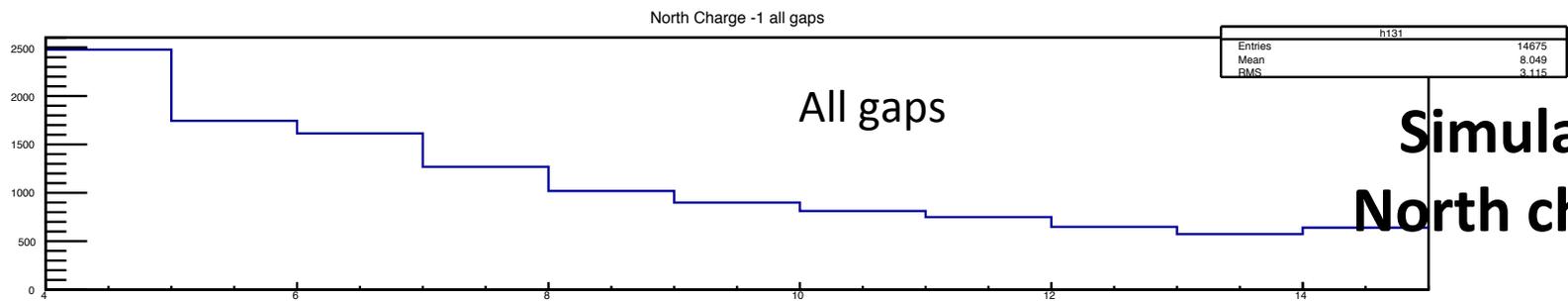
Ptot (GeV/c)

Simulation K+ South charge= +1

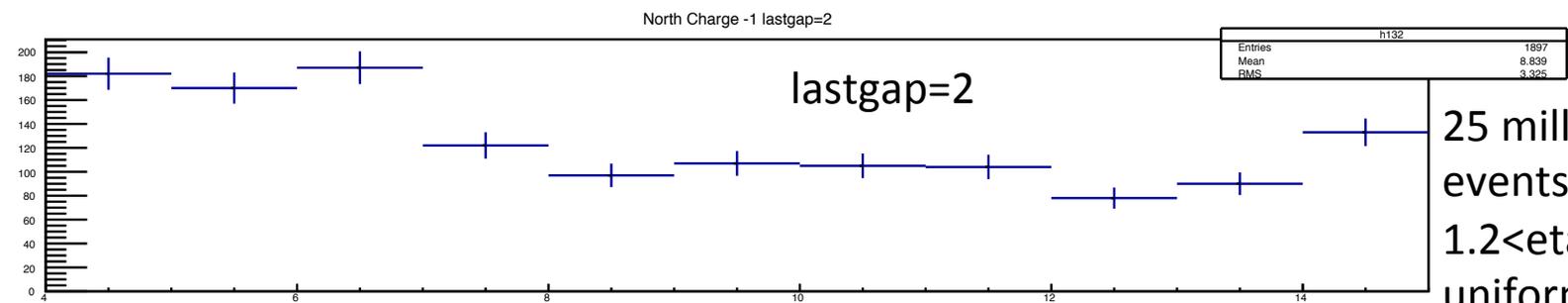


25 million initial events
 $1.2 < \eta < 2.4$
 uniform in solid angle
 $1.0 < p_{tot} < 20 \text{ GeV}/c$

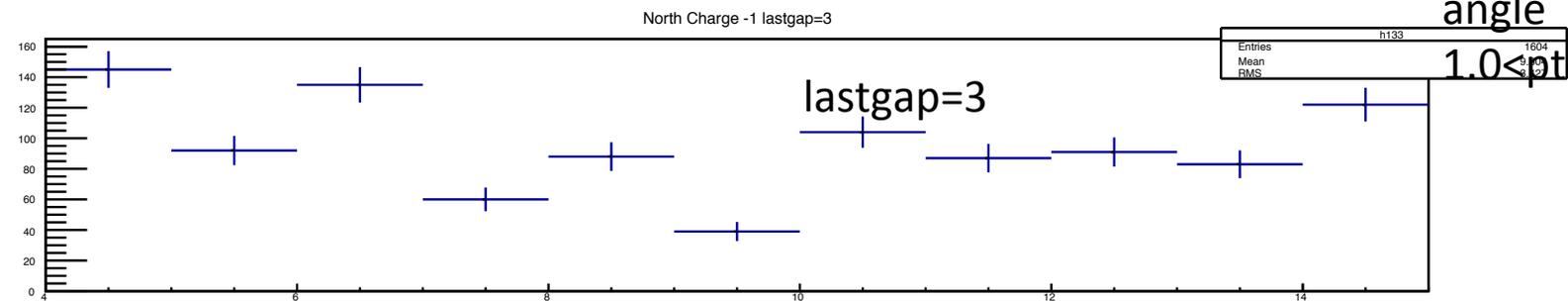
Ptot (GeV/c)



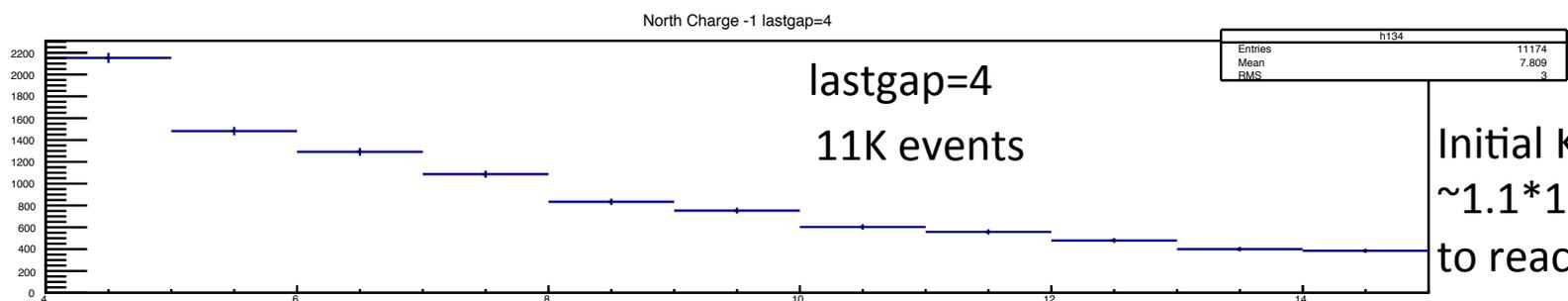
**Simulation K-
North charge= -1**



25 million initial events
1.2<eta<2.4
uniform in solid angle

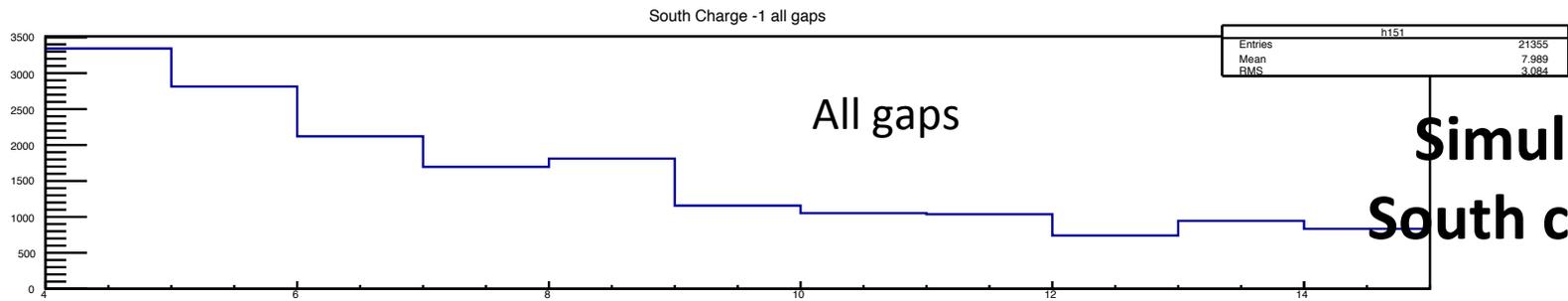


1.0<ptot<20 GeV/c

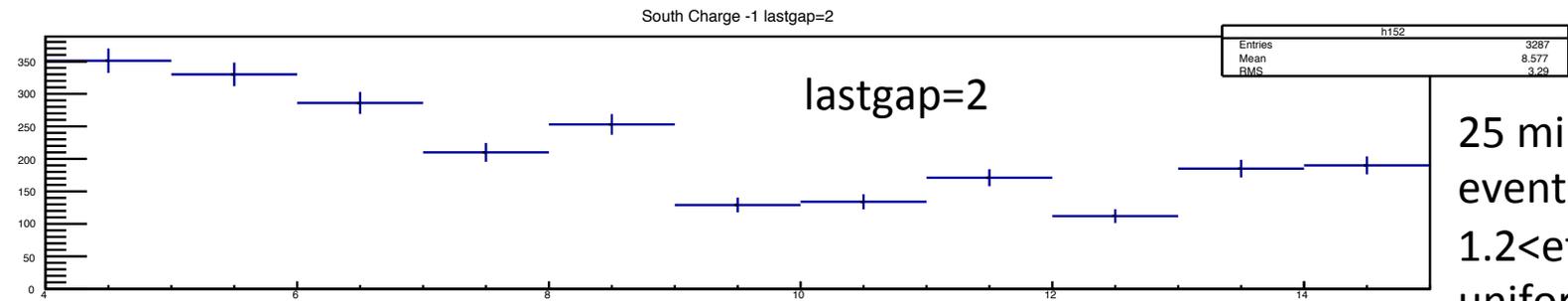


11K events
Initial K- events:
~1.1*10⁻³ prop.
to reach gap4

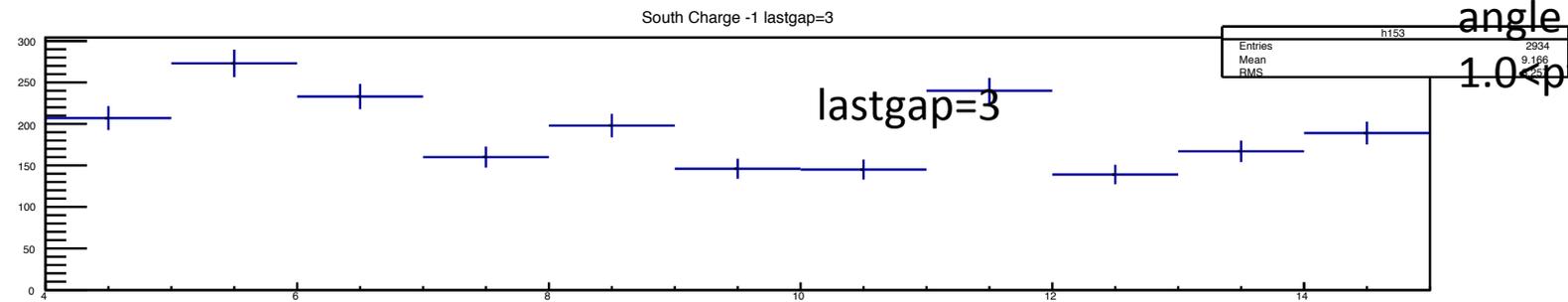
Ptot (GeV/c)



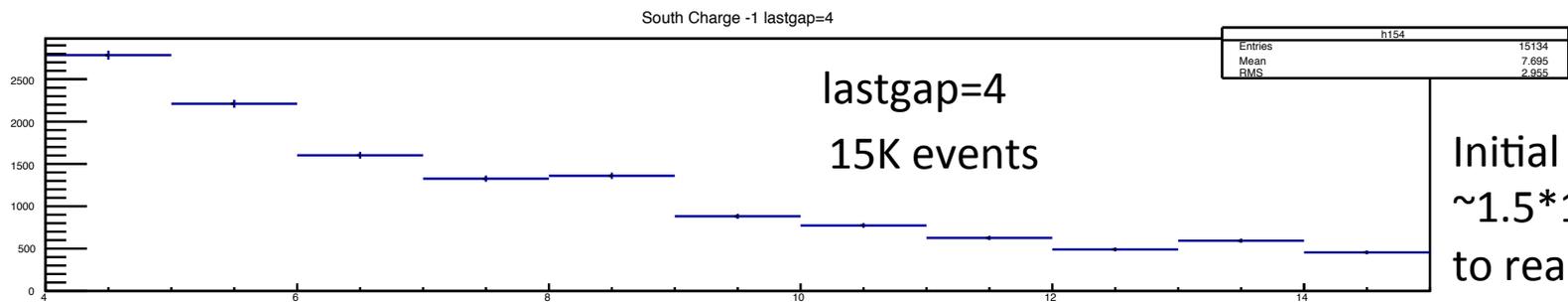
**Simulation K-
South charge= -1**



25 million initial events
1.2 < eta < 2.4
uniform in solid angle



1.0 < ptot < 20 GeV/c

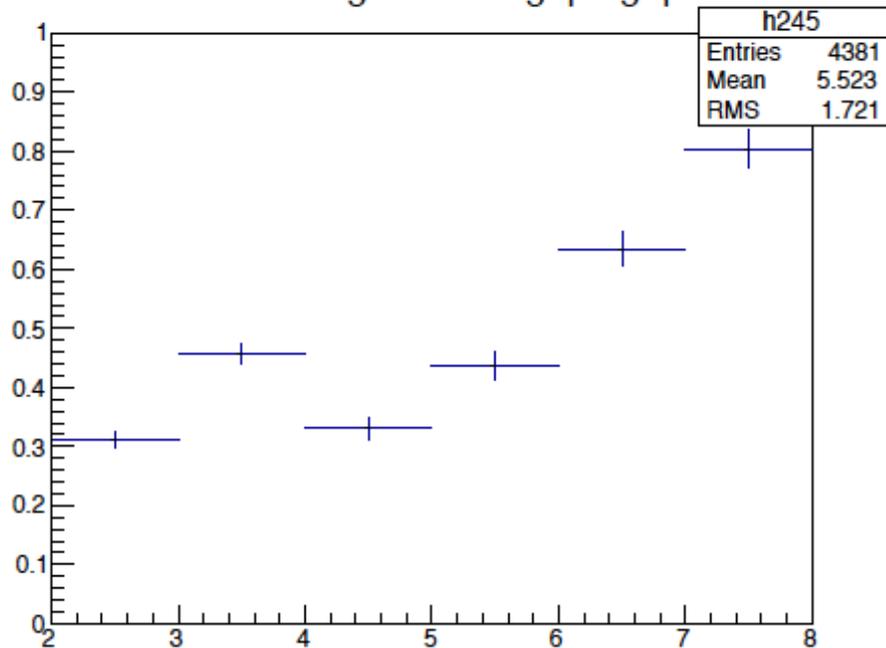


lastgap=4
15K events

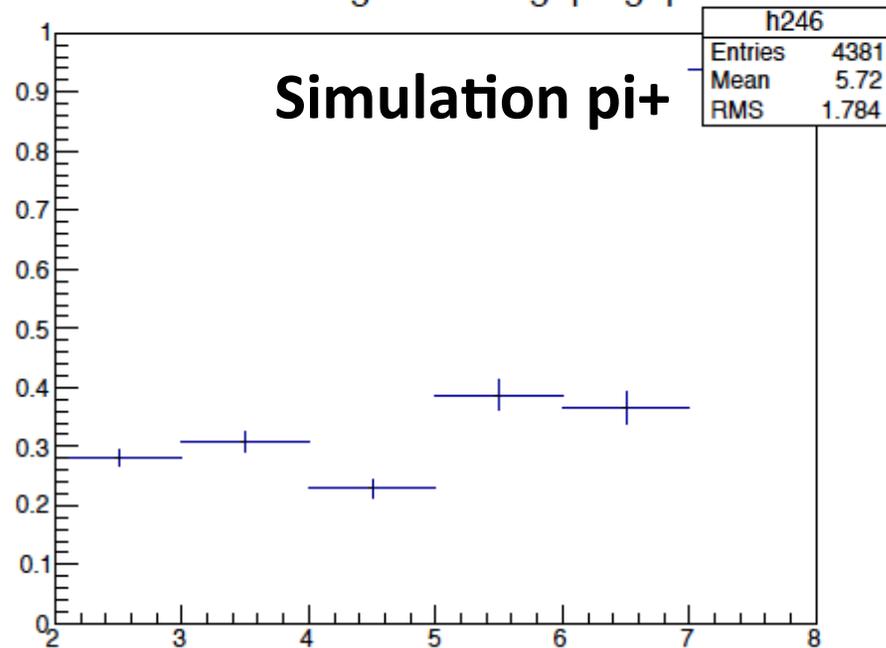
Initial K- events:
~1.5 * 10⁻³ prop.
to reach gap4

Ptot (GeV/c)

North Charge 1 ratio gap2/gap4

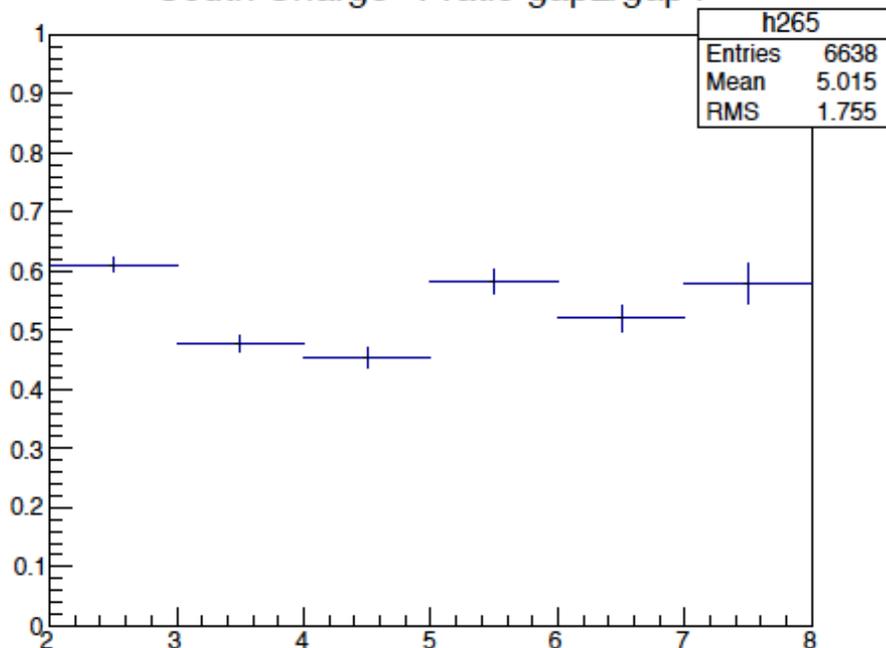


North Charge 1 ratio gap3/gap4

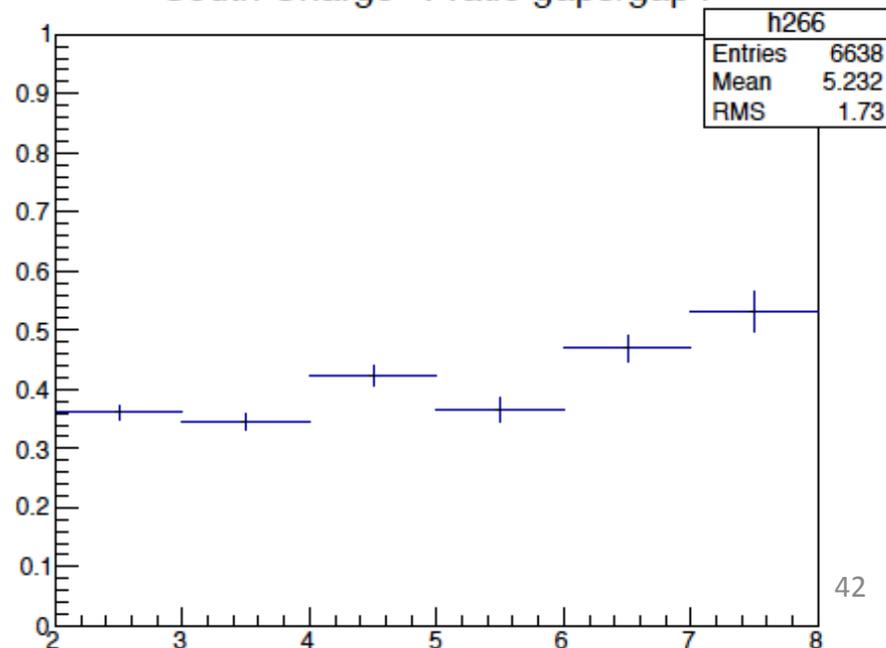


Pt (GeV/c)

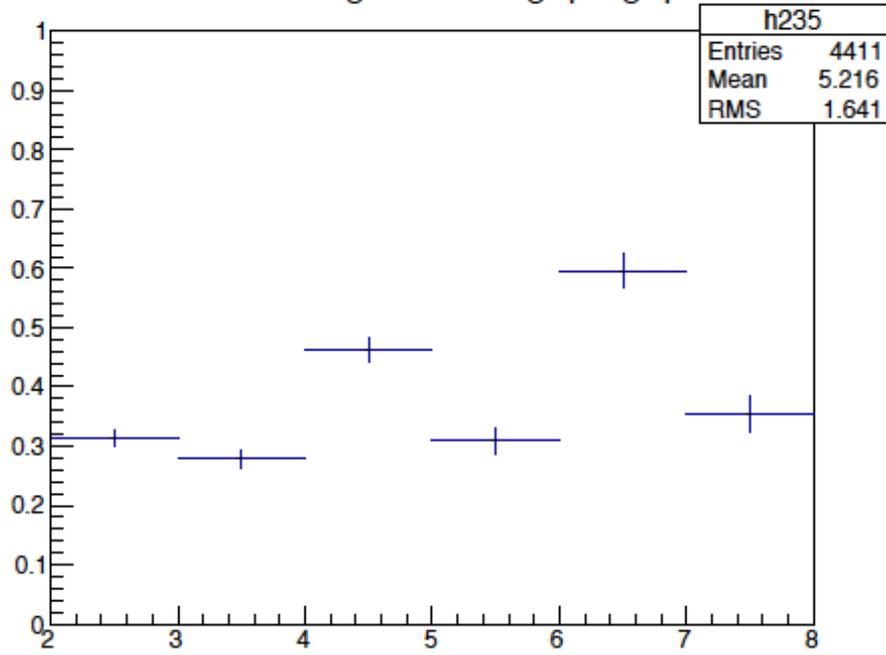
South Charge 1 ratio gap2/gap4



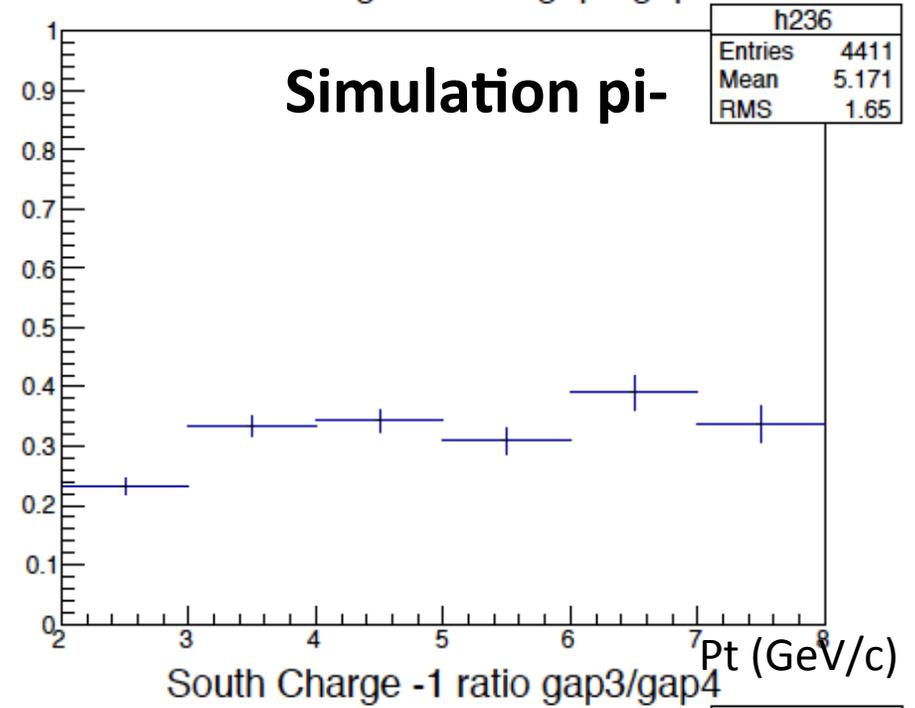
South Charge 1 ratio gap3/gap4



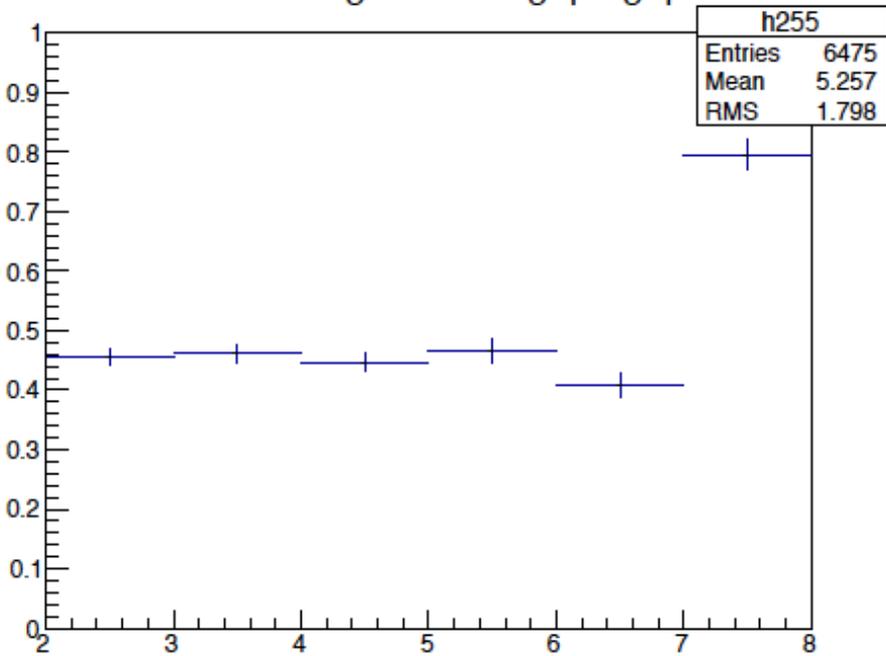
North Charge -1 ratio gap2/gap4



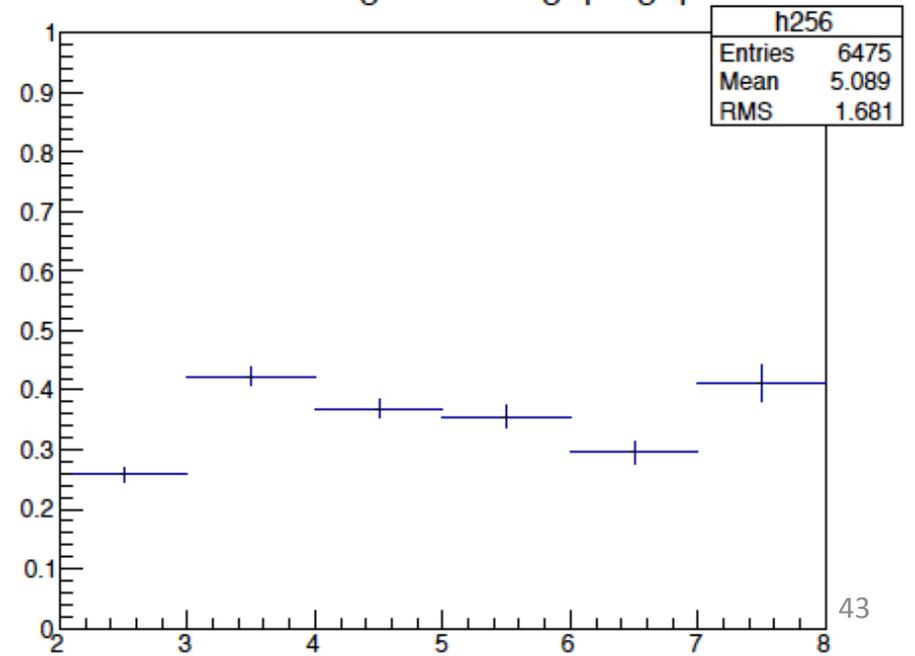
North Charge -1 ratio gap3/gap4



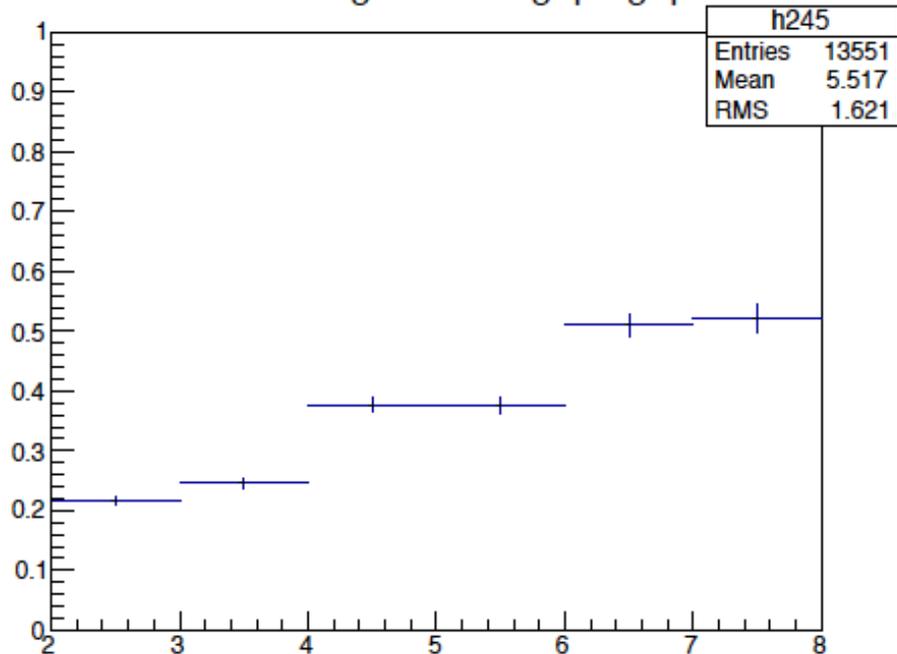
South Charge -1 ratio gap2/gap4



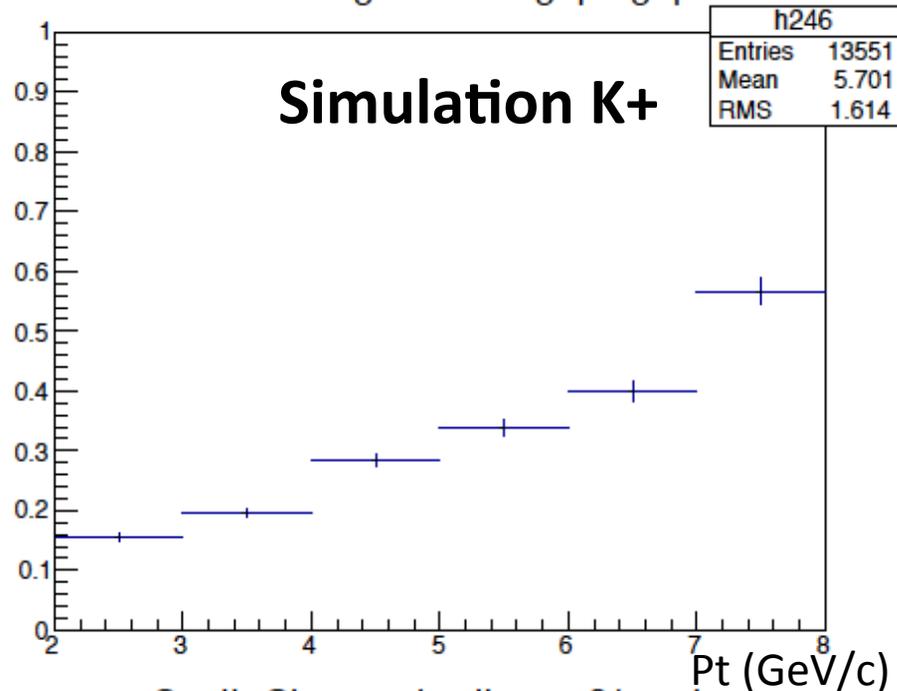
South Charge -1 ratio gap3/gap4



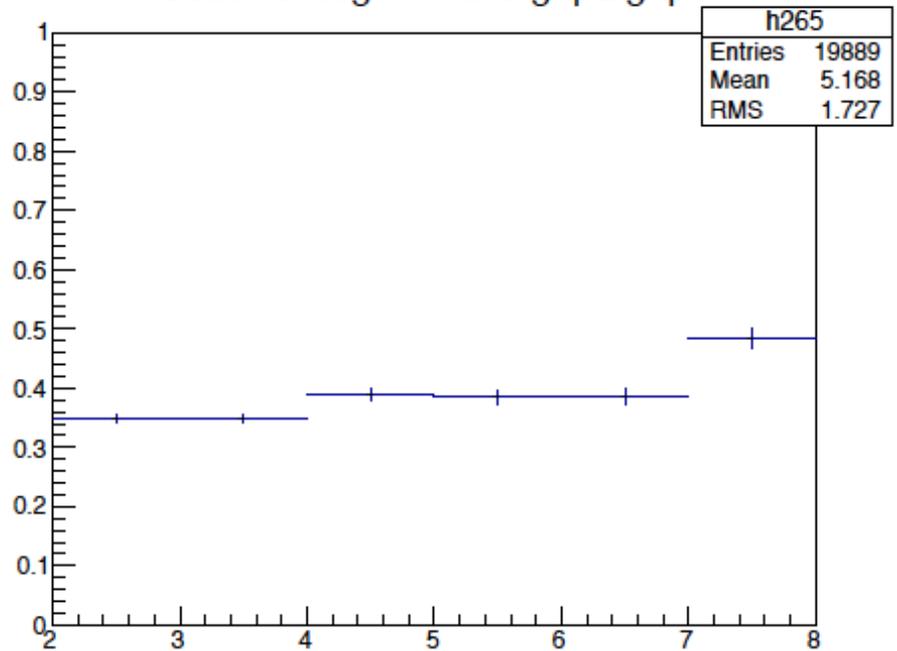
North Charge 1 ratio gap2/gap4



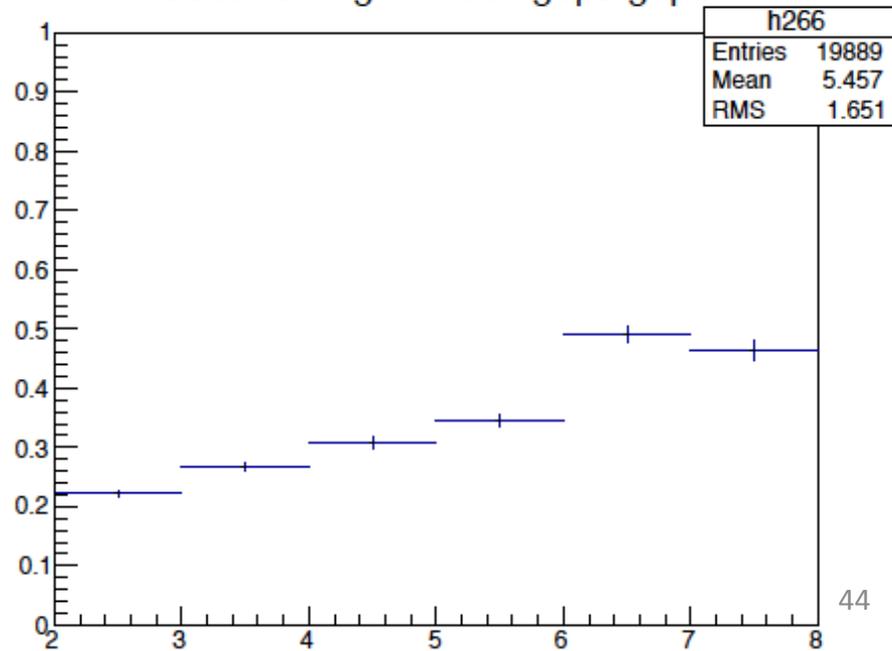
North Charge 1 ratio gap3/gap4



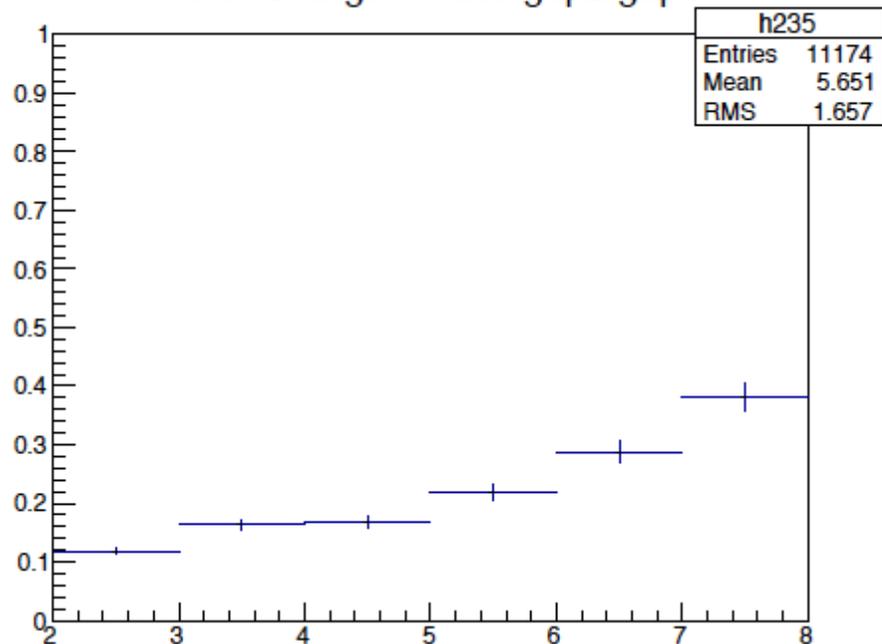
South Charge 1 ratio gap2/gap4



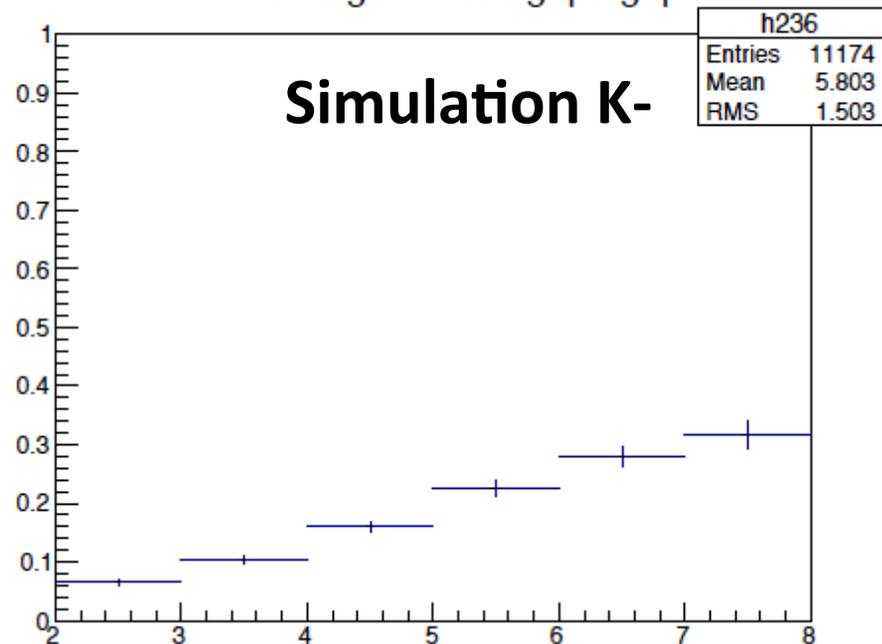
South Charge 1 ratio gap3/gap4



North Charge -1 ratio gap2/gap4

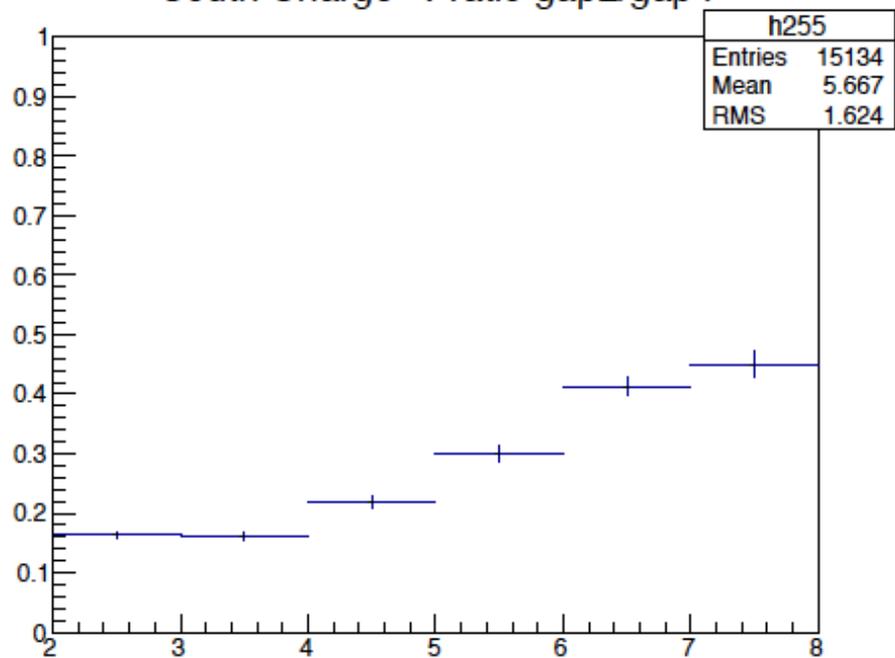


North Charge -1 ratio gap3/gap4

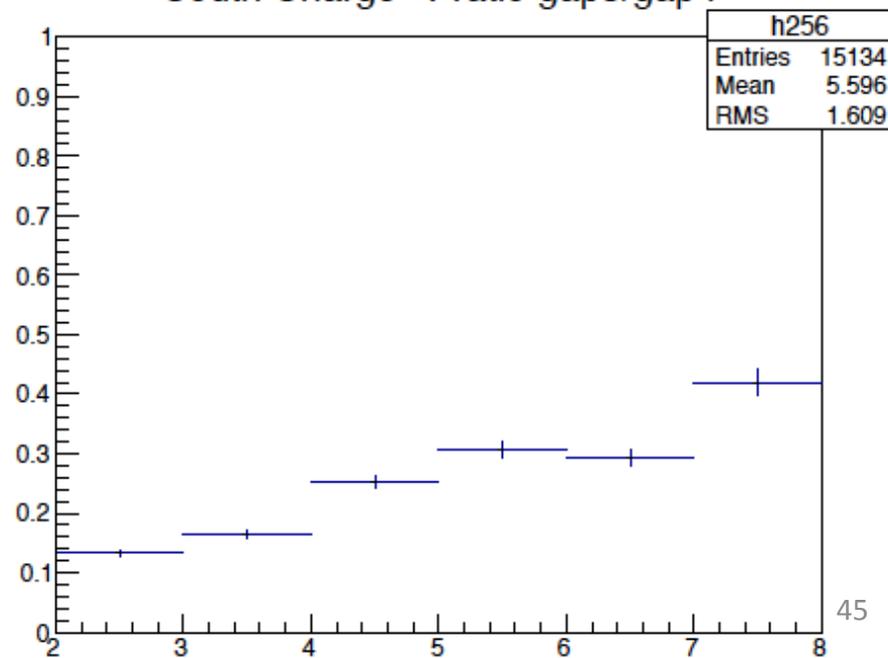


Pt (GeV/c)

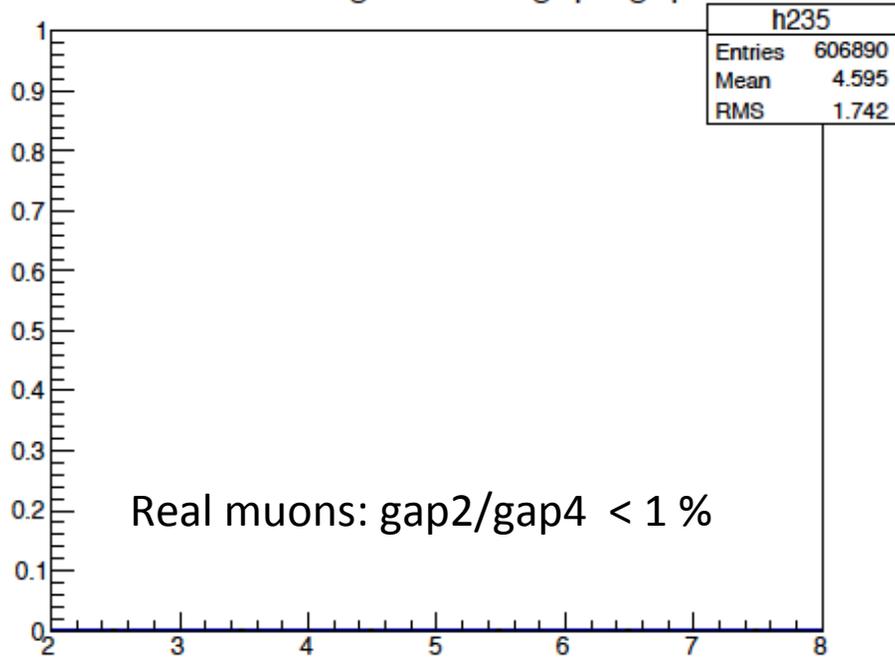
South Charge -1 ratio gap2/gap4



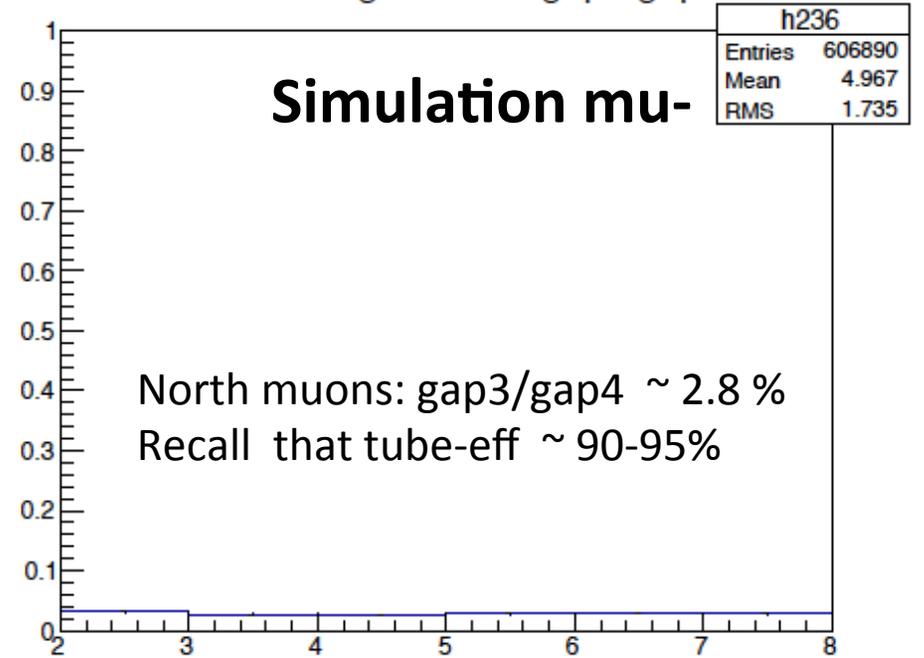
South Charge -1 ratio gap3/gap4



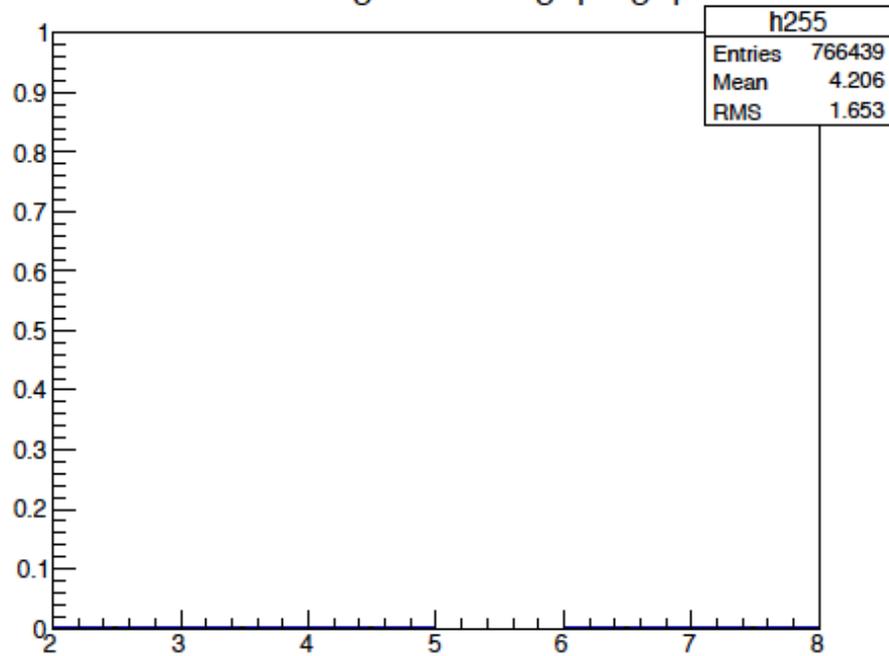
North Charge -1 ratio gap2/gap4



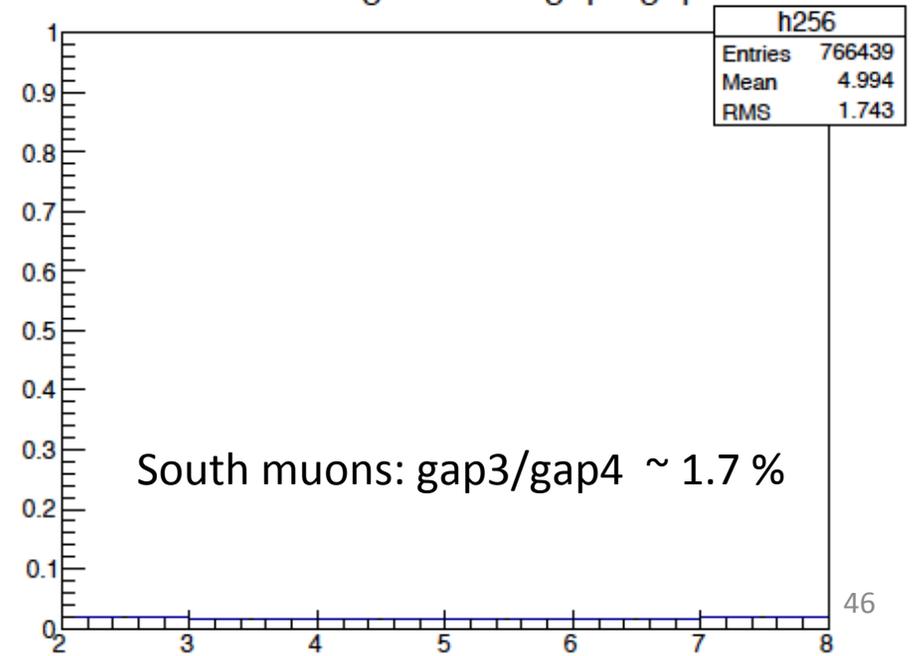
North Charge -1 ratio gap3/gap4



South Charge -1 ratio gap2/gap4



South Charge -1 ratio gap3/gap4

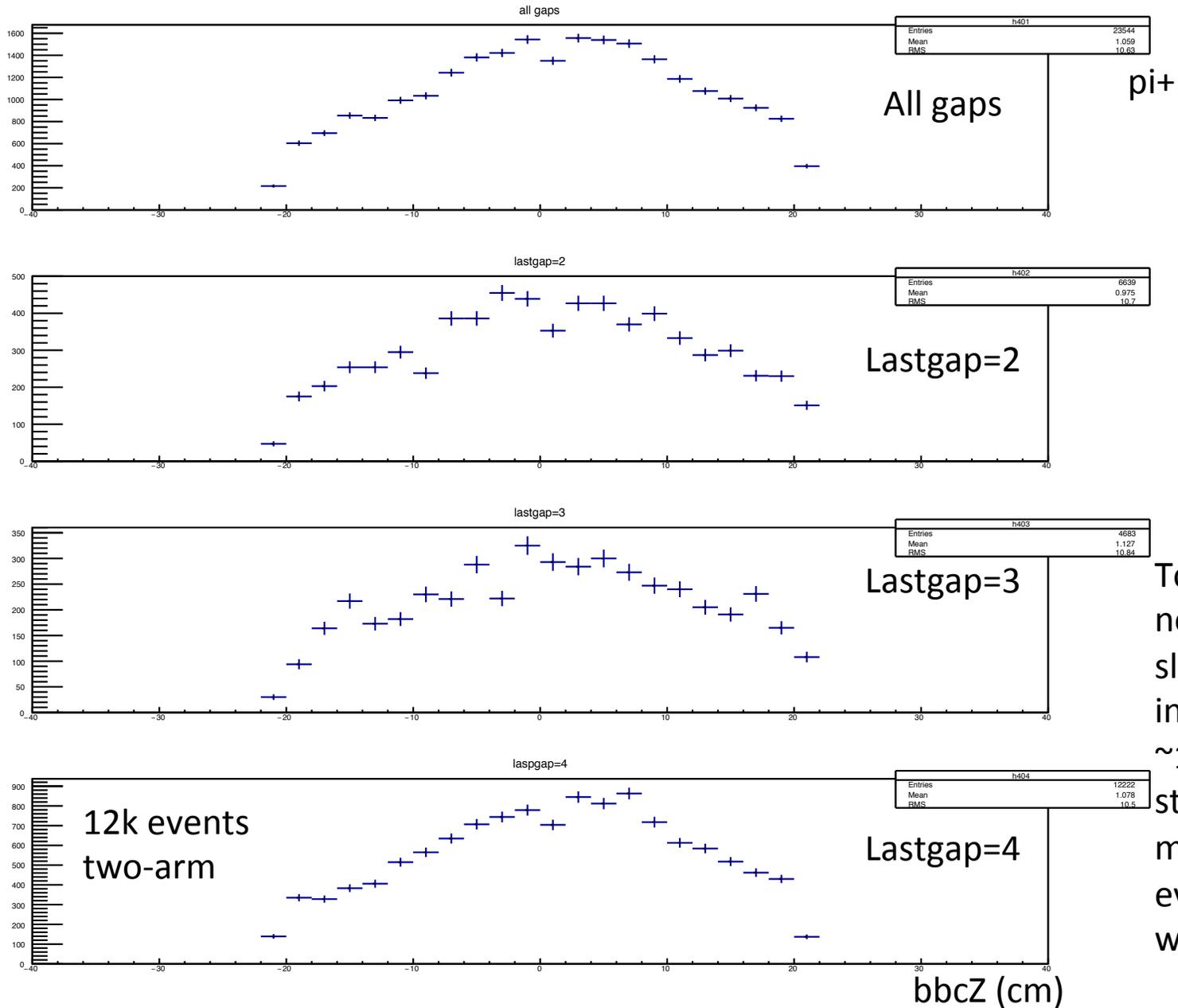


Pt (GeV/c)

Matching Simulations with Data

- Probability of hadron decay, as in dN/dz normalized bbcZ distributions.

Simulation Results: Vertex Distributions



pi+

All gaps

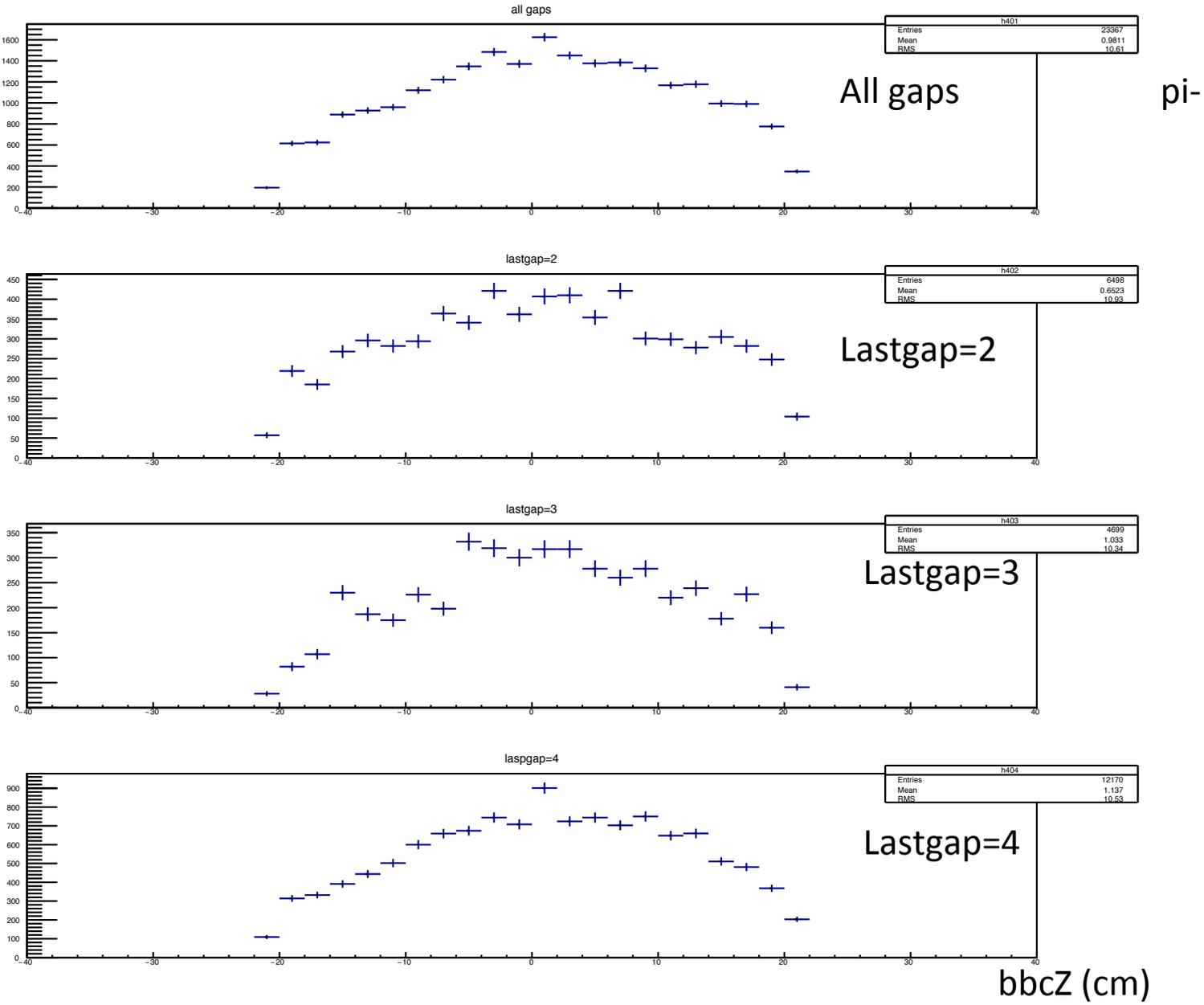
Lastgap=2

Lastgap=3

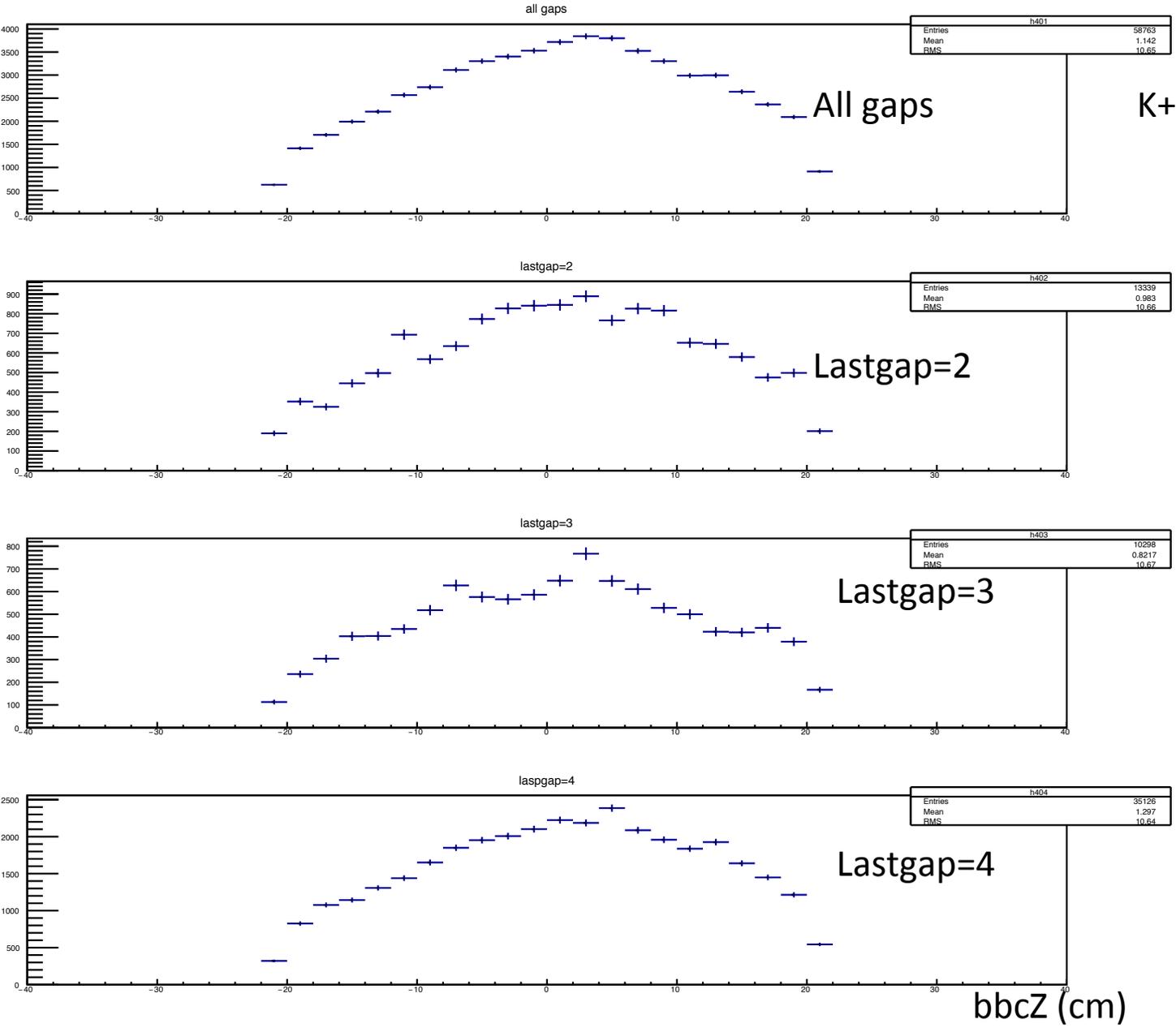
Lastgap=4

To obtain normalized dN/dz slope for 7 pt bins in each arm, wish ~10x more statistics. (~250 million initial events. i.e. >10 weeks at rcf.)

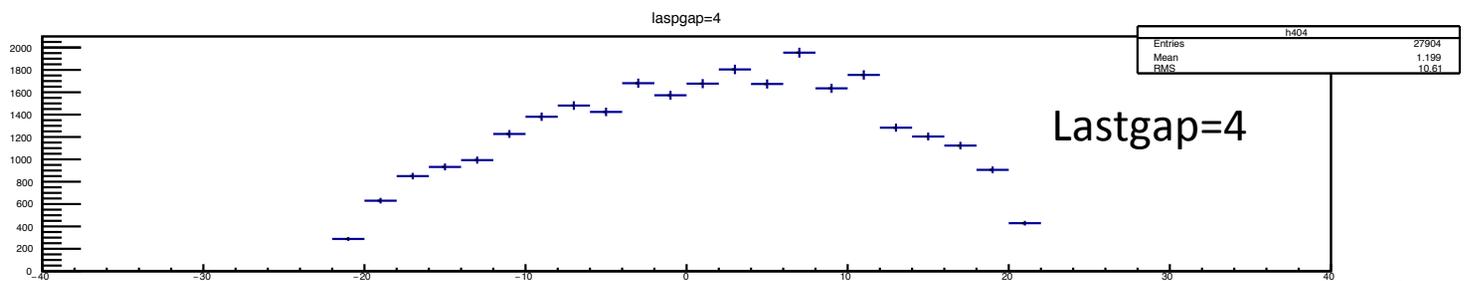
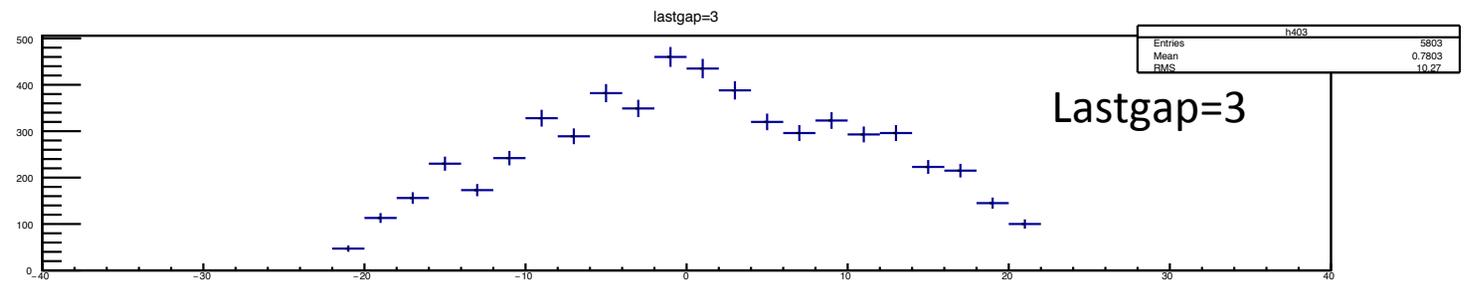
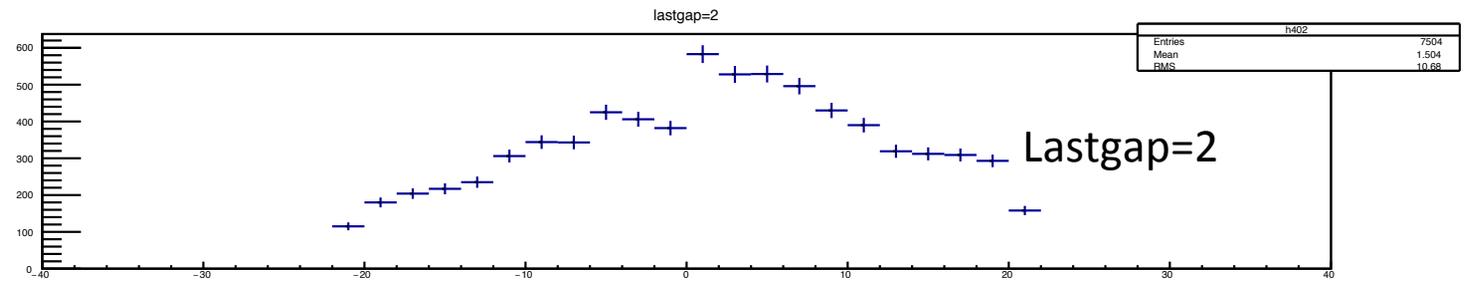
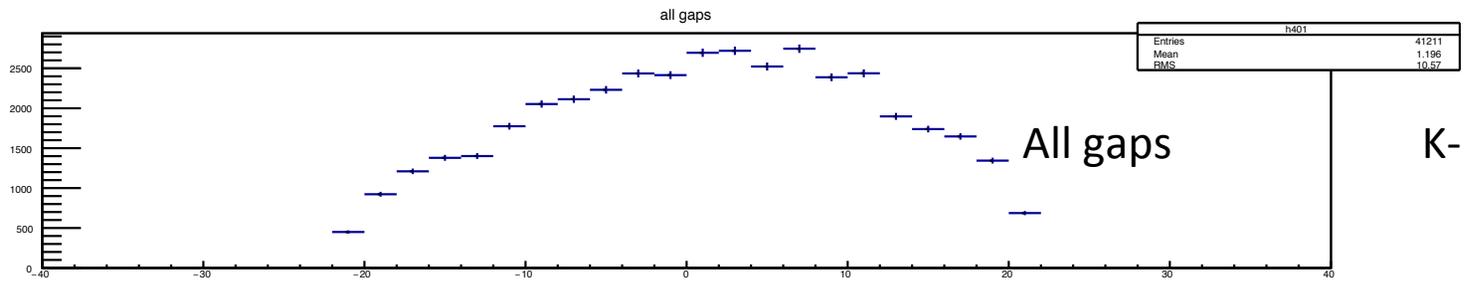
Simulation Results: Vertex Distributions



Simulation Results: Vertex Distributions



Simulation Results: Vertex Distributions



bbcZ (cm)

Simulation-II: Use Pythia8 Minimum Bias Event Generator as the Initial Inputs

- Rely on Pythia8 momentum distribution as the initial inputs.
- Rely on Pythia8 eta distribution as the “fixed” inputs.
- Rely on Pythia8 generated K/pi ratio as the “fixed” inputs.

The default path:

Pythia8 -> Geant4 Model -> Detector hits -> Track Reconstruction

-> momentum distributions for events with lastgap=3, 4

-> at each pt bin, adjust the “initial hadron fraction” to match simulation dN/dz slopes with data for lastgap=4 events.

Geant4 part of the simulation is extremely CPU-hungry

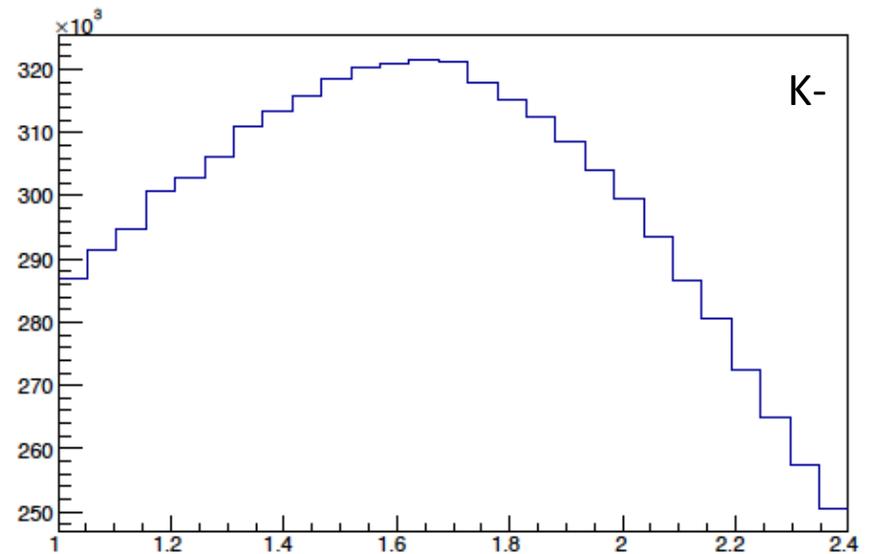
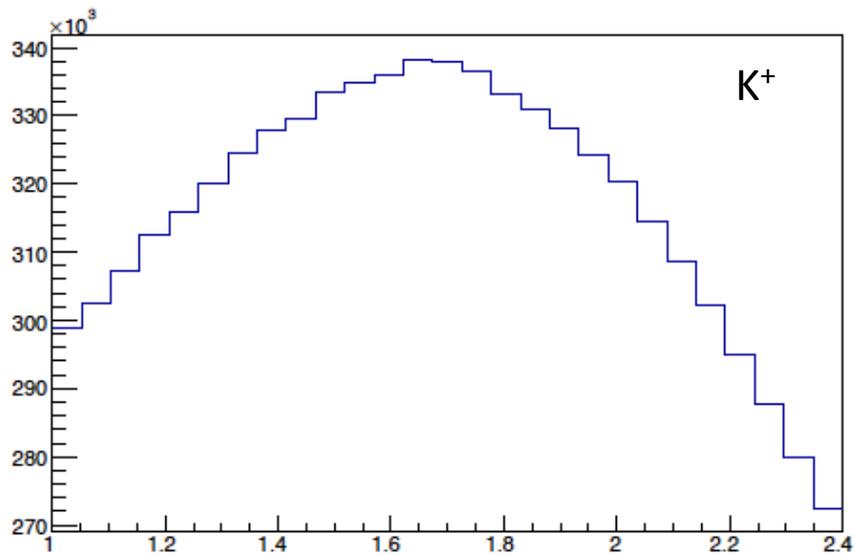
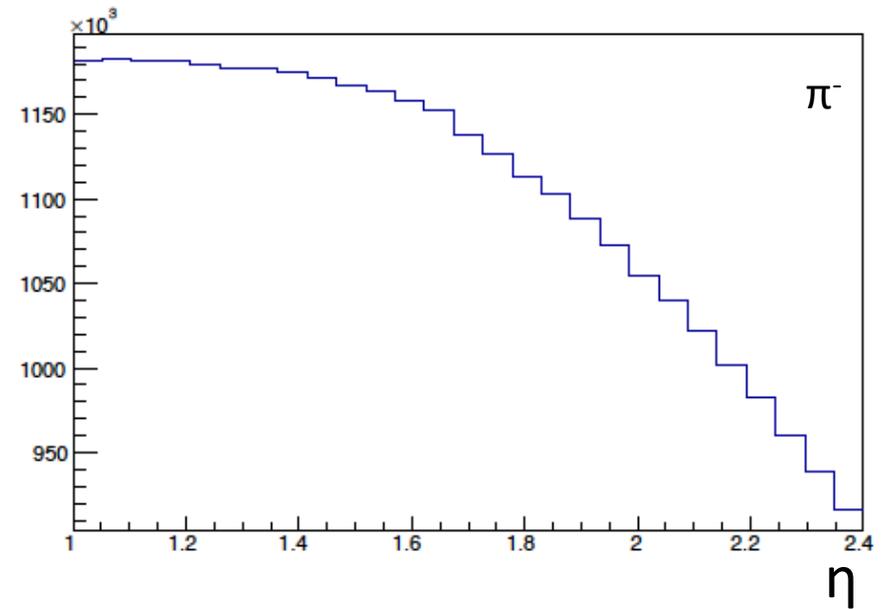
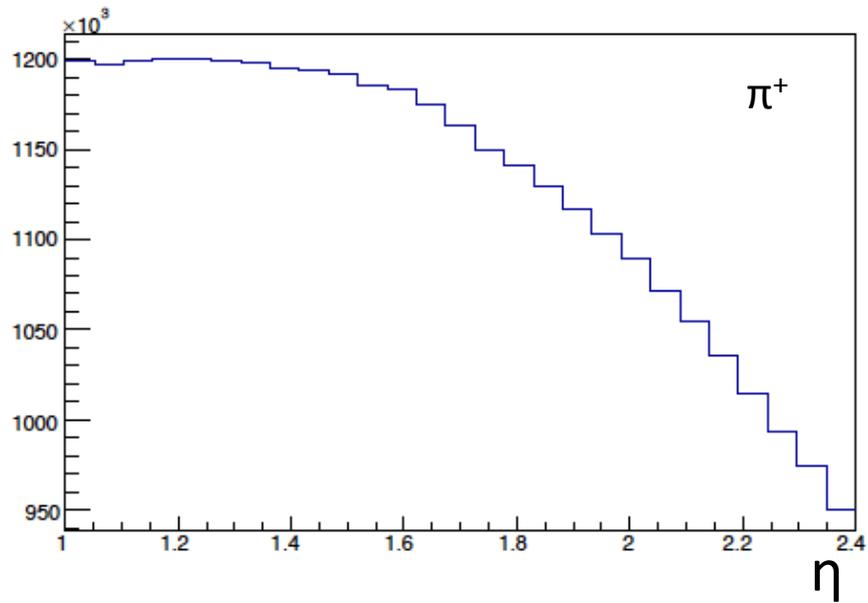
At RHIC computing clusters (rcf), a typical job of 1k Pythia8 MB events takes 1-CPU core 6 hours. At the end, 4 tracks reach MuTr, with $pt < 2.0$ GeV. No track reach MuID.

Need 10 simulation jobs (1k event each), to generate one MuID gap4 track.

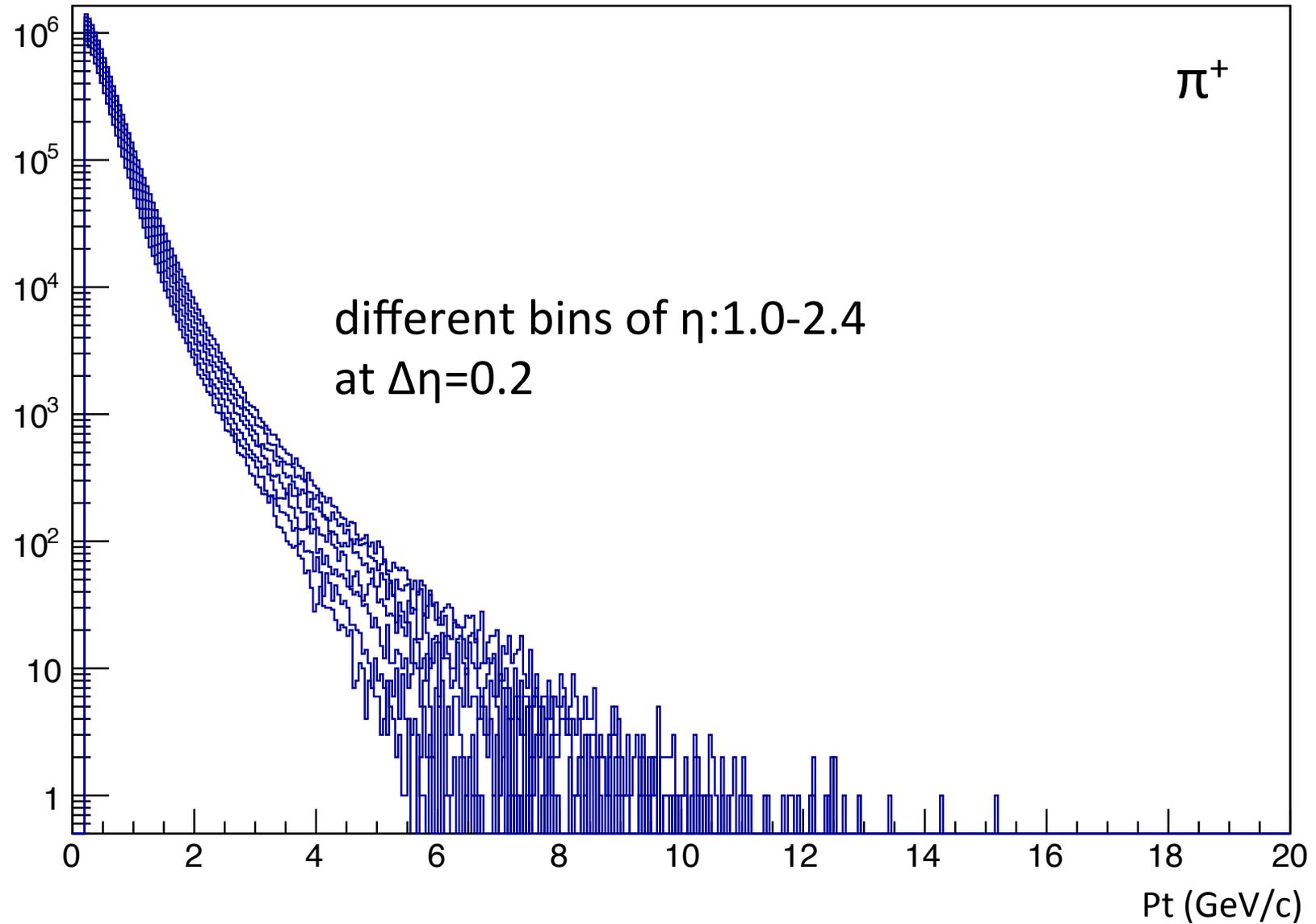
Need at least $\sim 10^6$ simulation jobs to obtain 100k (initial hadron) tracks in MuID.

Running on Open Scientific Grid for the past two months (Matt Snowball), with 100% MuID eff.

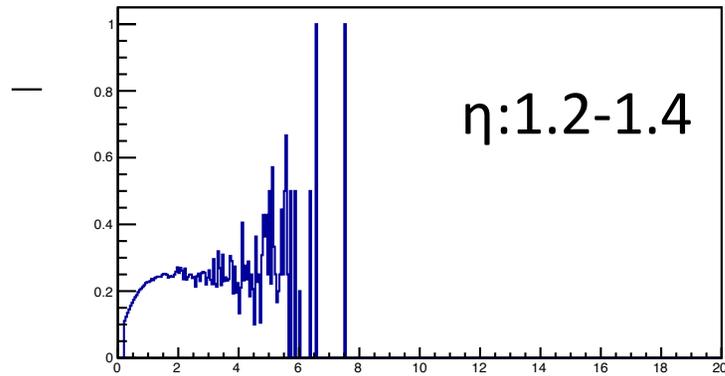
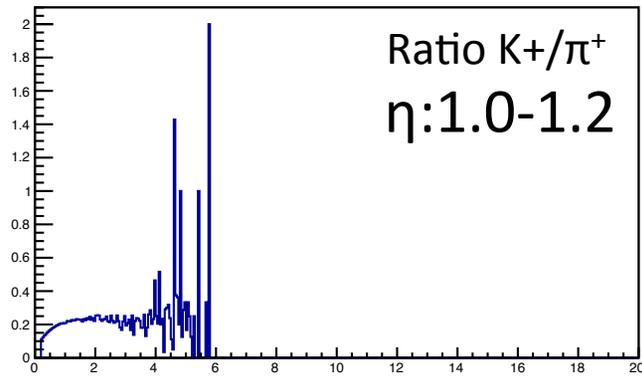
Pythia8 Generated Minimum Bias Events p+p at 510 GeV: eta distributions (35 Million MB events, before passing through GEANT4 model)



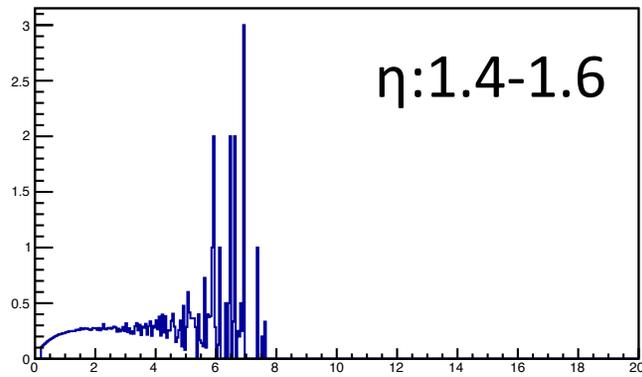
Pythia8 Generated Minimum Bias Events p+p at 510 GeV: π^+ Pt distribution
(35 Million MB events, before passing through GEANT4 model)



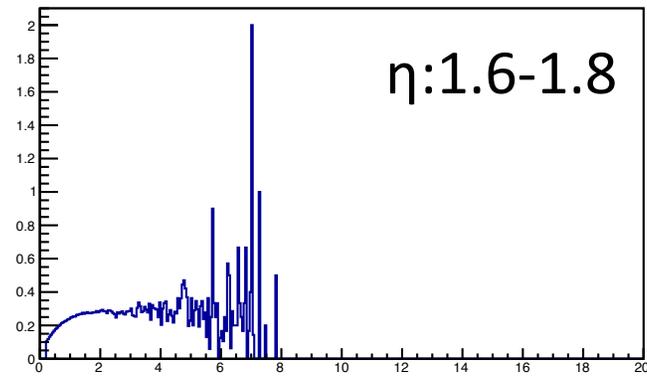
Pythia8 Generated Minimum Bias Events p+p at 510 GeV: ratio $K^+/\pi^+ \approx 0.2-0.3$



Pt (GeV/c)

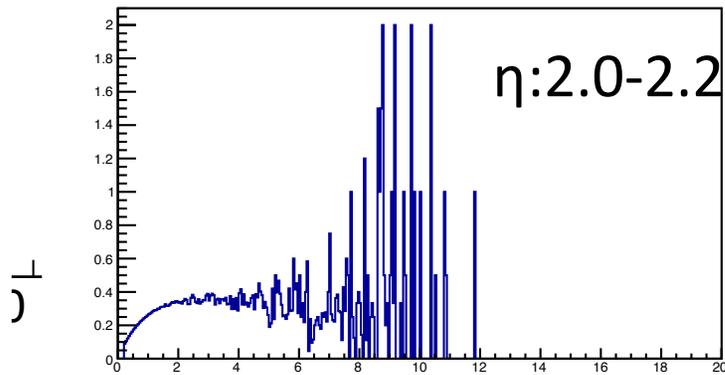
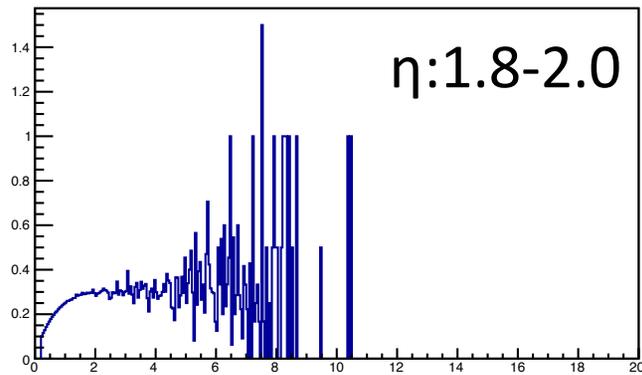


K^+



π^+

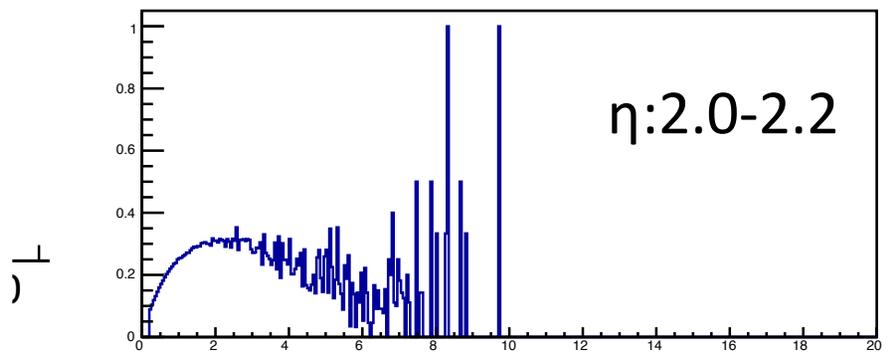
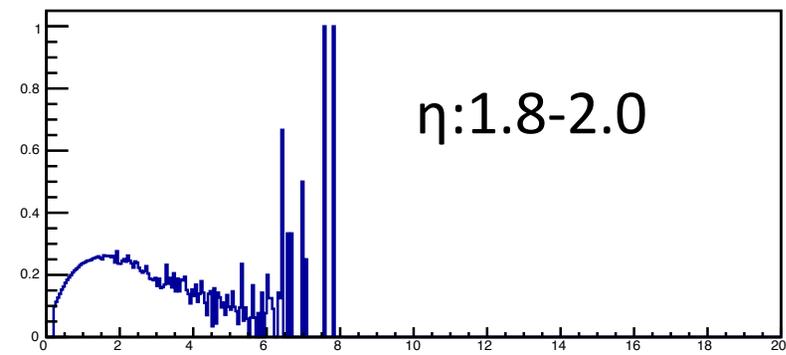
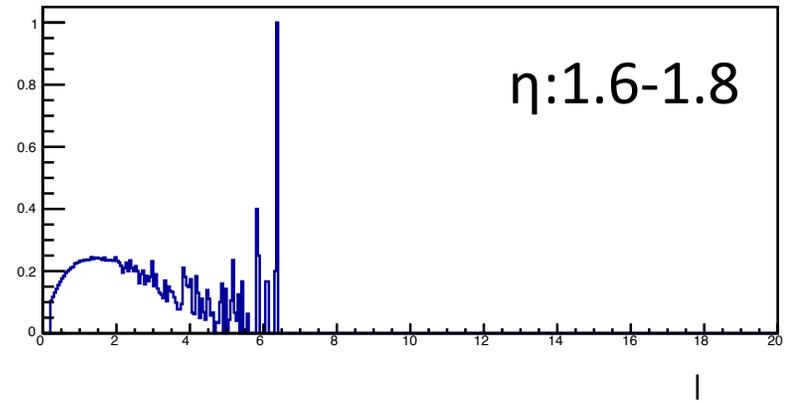
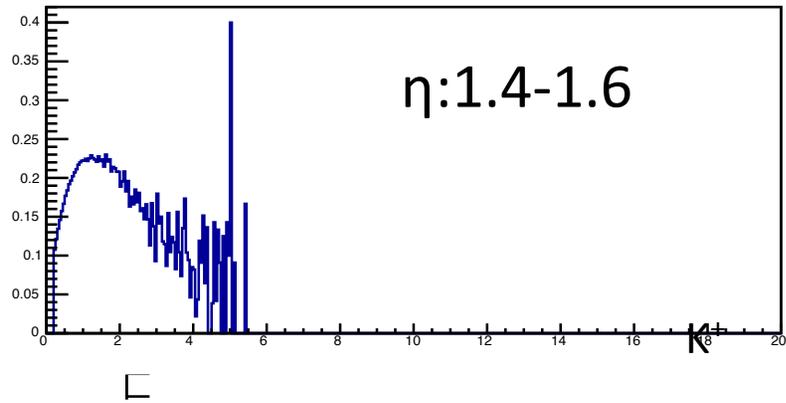
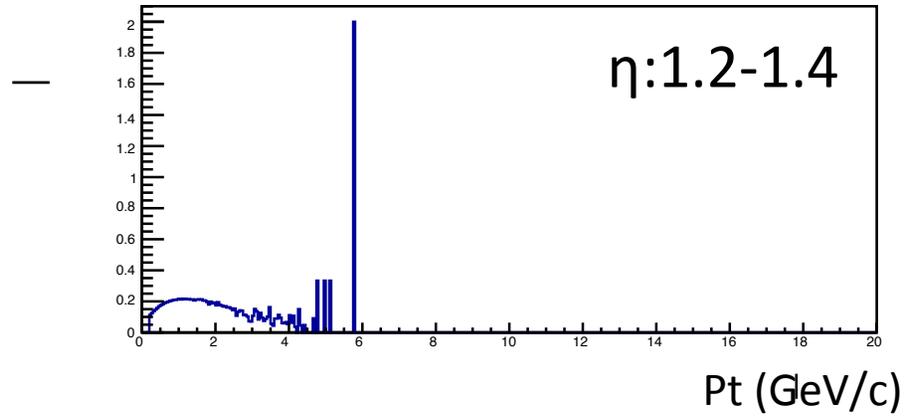
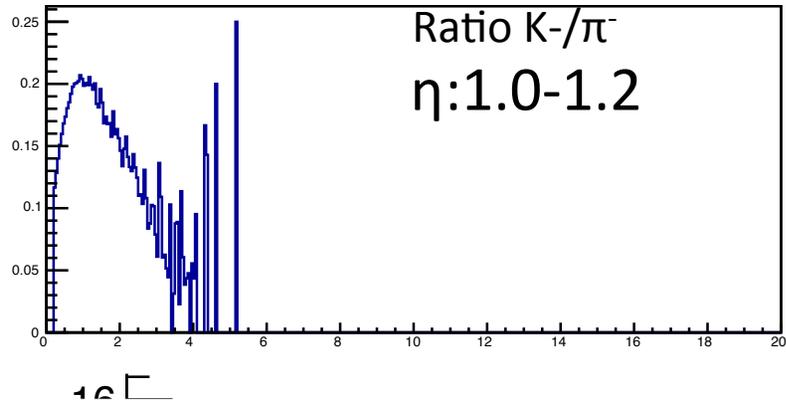
π^+



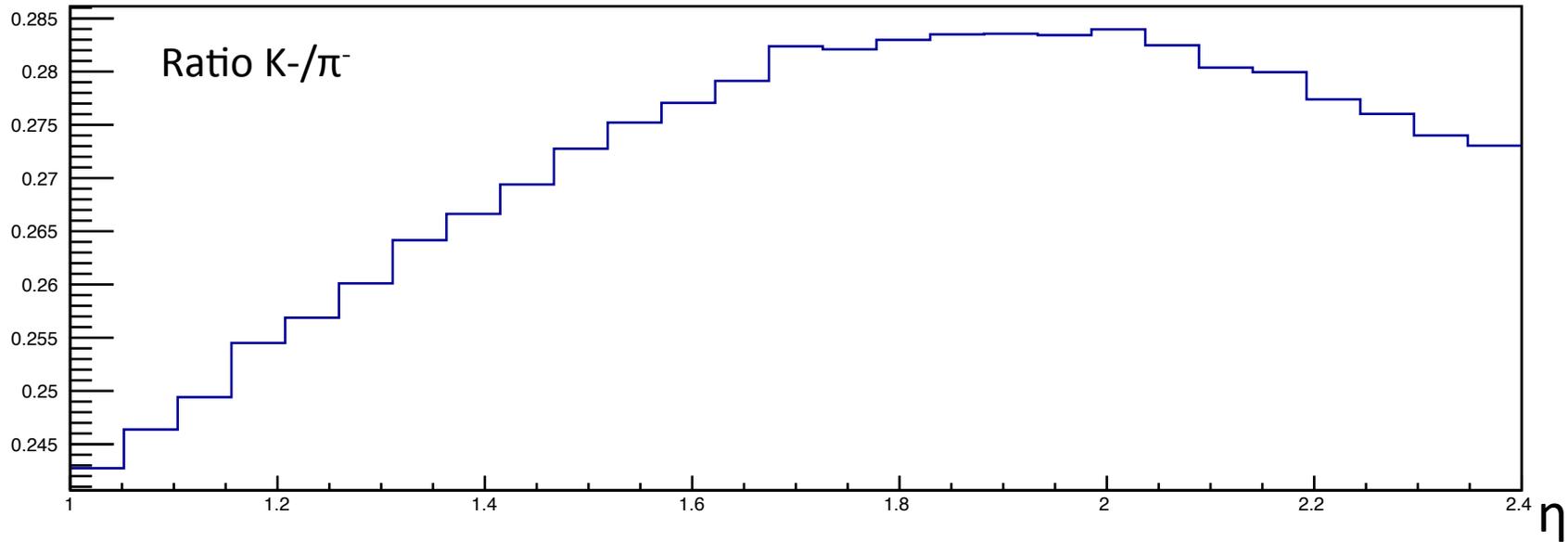
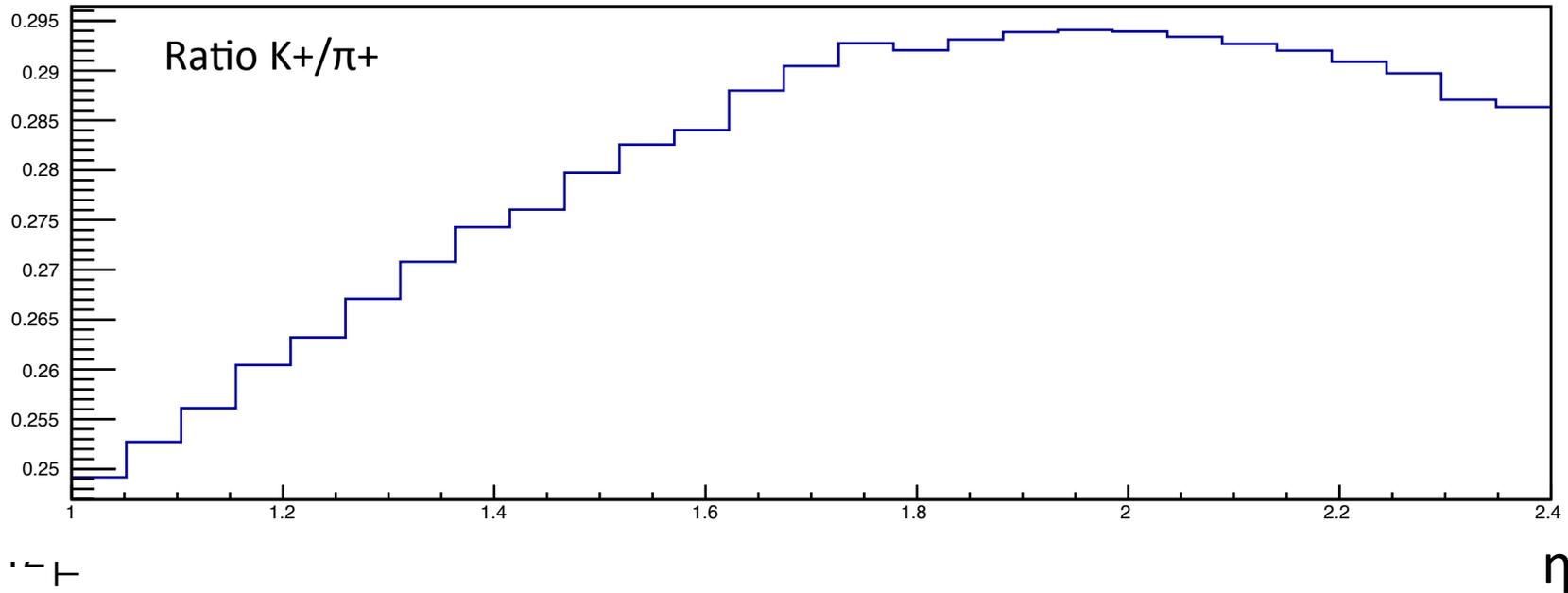
K^+

π^+

Pythia8 Generated Minimum Bias Events p+p at 510 GeV: ratio $K^-/\pi^- \approx 0.2-0.3$



Pythia8 Generated Minimum Bias Events p+p at 510 GeV



Follow up Steps in the Analysis:

1. Use pythia8's eta distribution, but with a flat momentum distributions. Simulate 250 million π^+ , π^- , K^+ , K^- event (take many weeks++).
2. Bin in p_T (7 bins), obtain dN/dz slopes for initial π , K .
3. Assume fixed K/π ratios, from pythia8, match dN/dz slope of simulation with data.
4. Do not insist on reproducing $\text{lastgap}=2, 3, 4$ relative relation at the same time. Focus on $\text{gap}_3, \text{gap}_4$ shapes, not much on gap_2 (i.e. do not trust on gap_2 events tracking quality).
5. Return to step-1, with "tuned momentum spectra". Repeat step-1 to step-4.

Took the outputs from MB simulated events (perfect MuID eff) on Open Scientific Grid, as inputs to step-1.

Need >500 GB disk storage space on rcf.

Investigate effects with different inputs of MuID efficiency:

5 million μon^{\pm} events simulated corresponding to MuID eff of HighLumi, and LowLumi cases (completed, took one week). Compare to perfect MuID efficiency case.

Backup Slides

Extracting Background Fractions in Single-Particle Yields to Obtain Prompt Muon Spectra

Goal: to obtain the “true prompt-muon yields” as a function of rapidity and P_{tot} (or P_t).

Issues: measured single-particle events contain

1. True prompt-muons (signal).
2. Initial hadrons that pass the detector and tracking cuts (background), either through decay to muons (DM) or punch through absorber (PH).

Need: to figure out “the fraction of events corresponding to initial-hadrons as the backgrounds in the measured single-particle sample”, and subtract these background.

Starting point, we trust the measurements of:

1. Single particle spectra in each arm, for events of lastgap=2 (??), 3(?), and 4.
2. Slope of bbcZ distribution (dN/dz) for lastgap=4 events, normalized to “no-selection”.
3. Knowledge of MuID tube efficiencies obtained through “traditional data-driven method”.

Trusted tools (GEANT4 simulation):

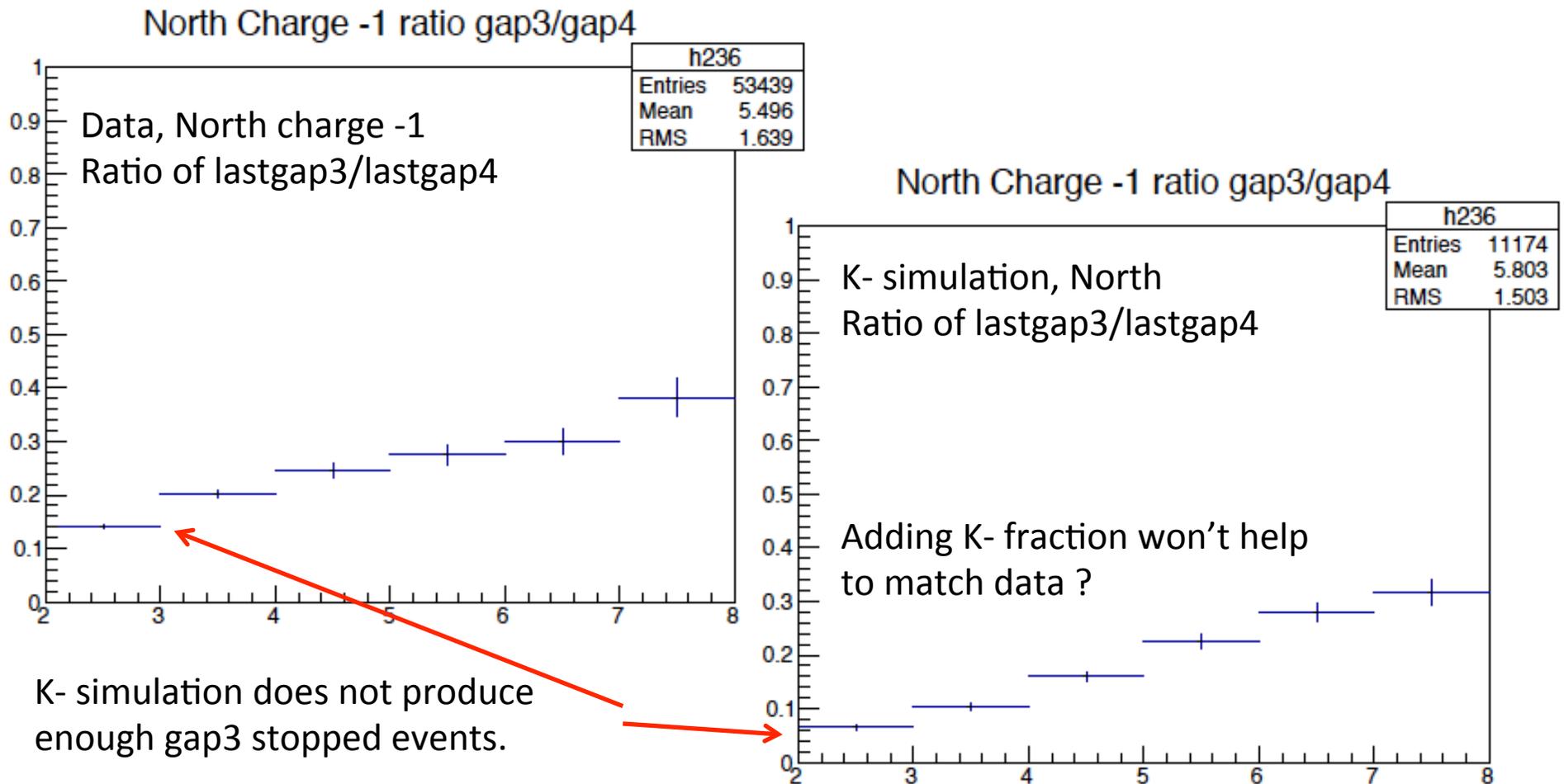
Considered well-known and effects well-reproduced in Geant4:

1. Effects due to Geometrical, nose cone and absorber material thickness, detector locations, size and active areas, dead channels and dead areas, magnetic field strength and shapes.
2. Effects such as particle decay, multiple scattering, ionization and radiation energy losses through material, etc.

The Default Procedure

1. Through GEANT4 simulations of single-particles (pion, Kaon, muon etc) originated at the vertex, produce single-particle spectra associated with lastgap=2, 3, 4 for simulated events pass through detector cuts. The initial rapidity, and momentum distributions of simulation can be either be uniform distributions, or obtained from Pythia8 based Minimum Bias simulations, to be re-adjusted in later steps.
2. For each arm, each charge, each momentum bins, TUNE the relative weighting of spectra in step-1, such that the final summed spectra match the shape of the measured data listed. Starting from lastgap=4 events dN/dz shape. Also wish to match the momentum shape of laspgap=3.
3. Re-iterate, back to step-1, use the obtained relative weighting through step-2 to re-adjust the initial momentum distributions. When best-matched with data, obtain the “initial hadron fractions” as the background. Obtain the “true prompt-muon” spectra.
4. Addressing uncertainties due to MuID-detector inefficiency.
Repeat step-1 through step-3, with different MuID tube efficiency files.
The differences in the outcome will be taken as part of the systematic uncertainties introduced in this analysis method.

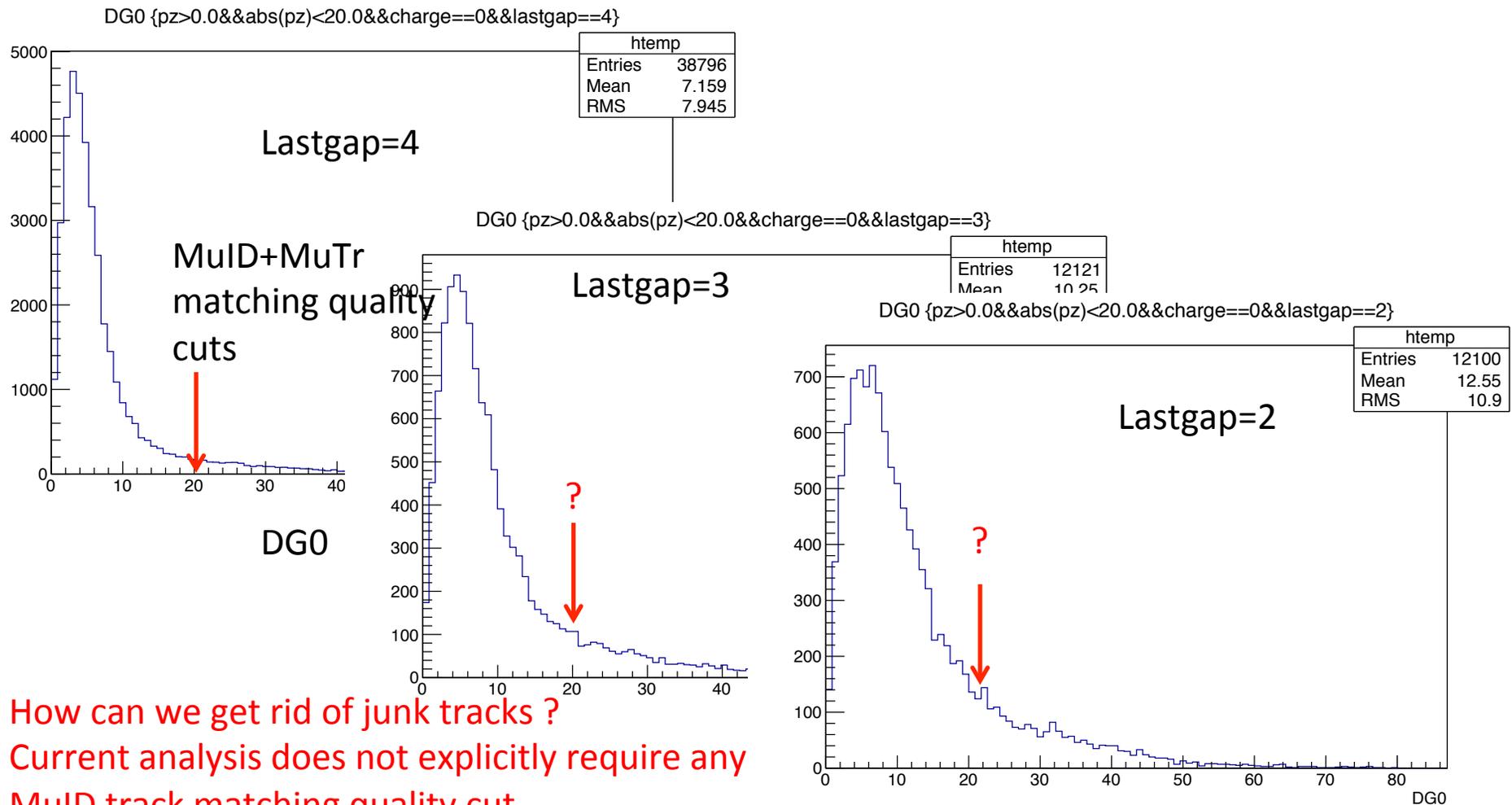
Known Issues in simulation: not enough Kaons stop in lastgap=3



take K- and pi- fractions as independent unknowns,
Leads to solutions of “negative K- fraction” in order to fit both lastgap=2, lastgap=3,
relative to lastgap=4.

Known Issues in data: track quality not easily controlled for lastgap=2,3 events

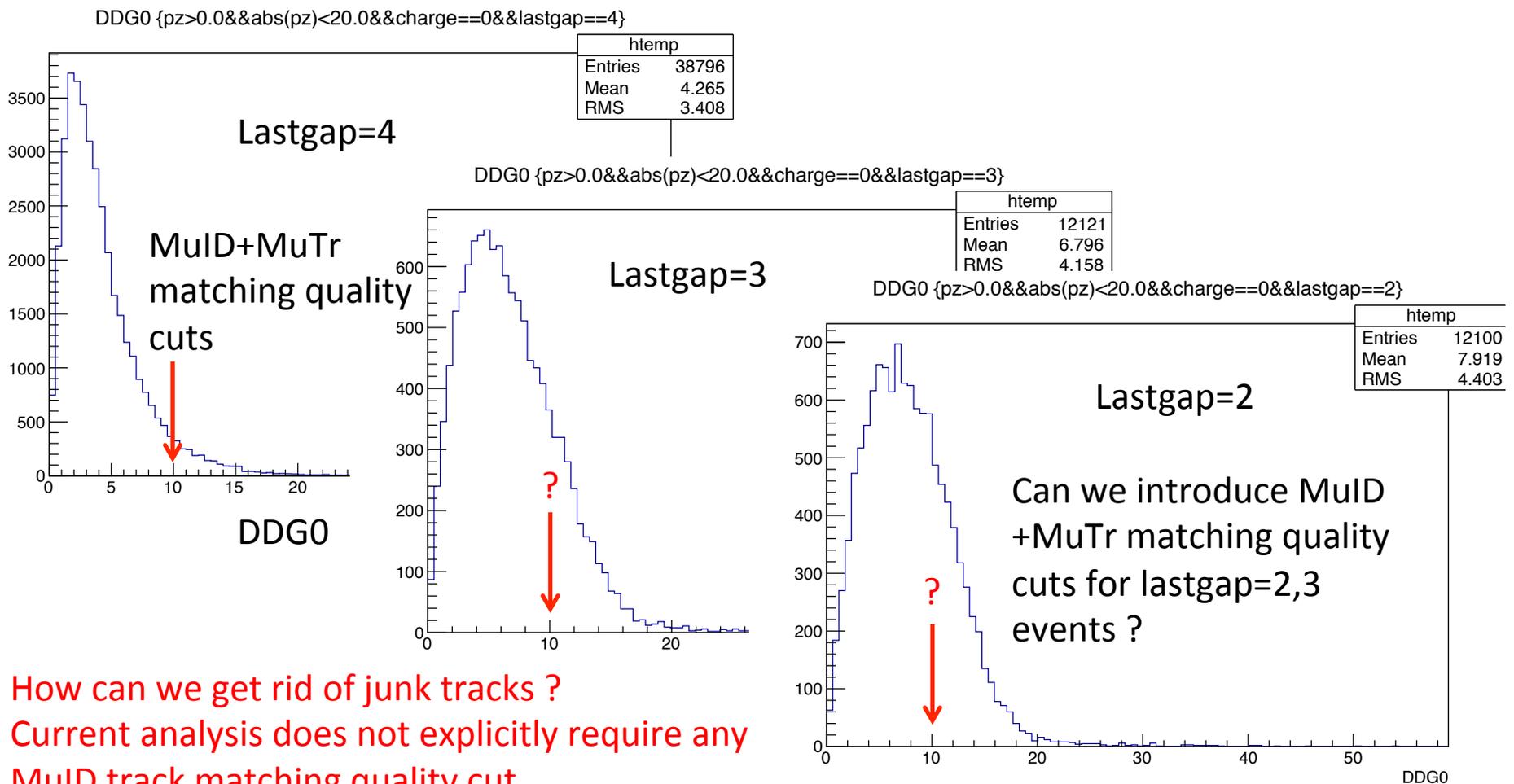
In MB triggered events, lastgap=2, 3 events do not have a good control on matching MuID roads with MuTr tracks.



How can we get rid of junk tracks ?
Current analysis does not explicitly require any MuID track matching quality cut.

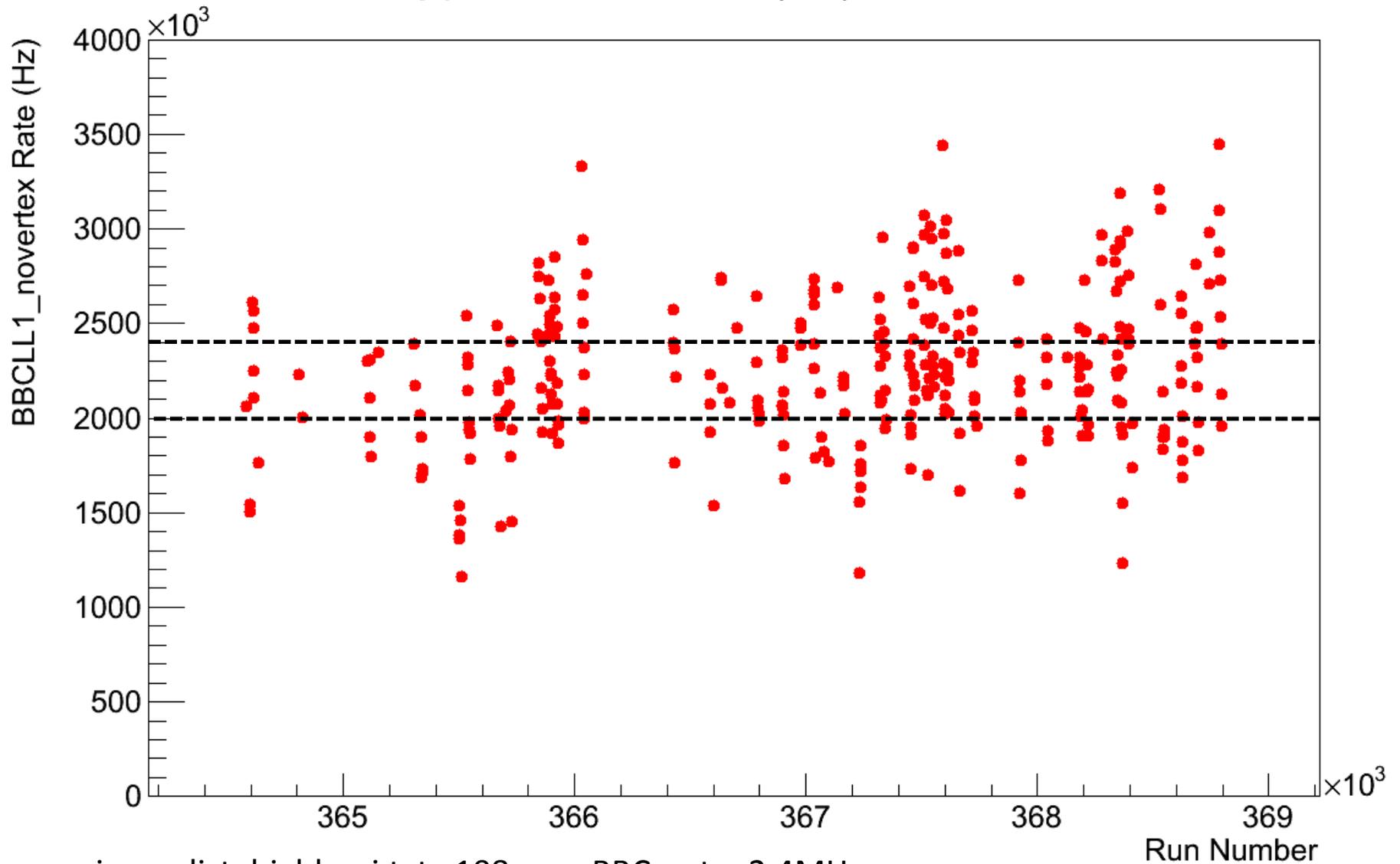
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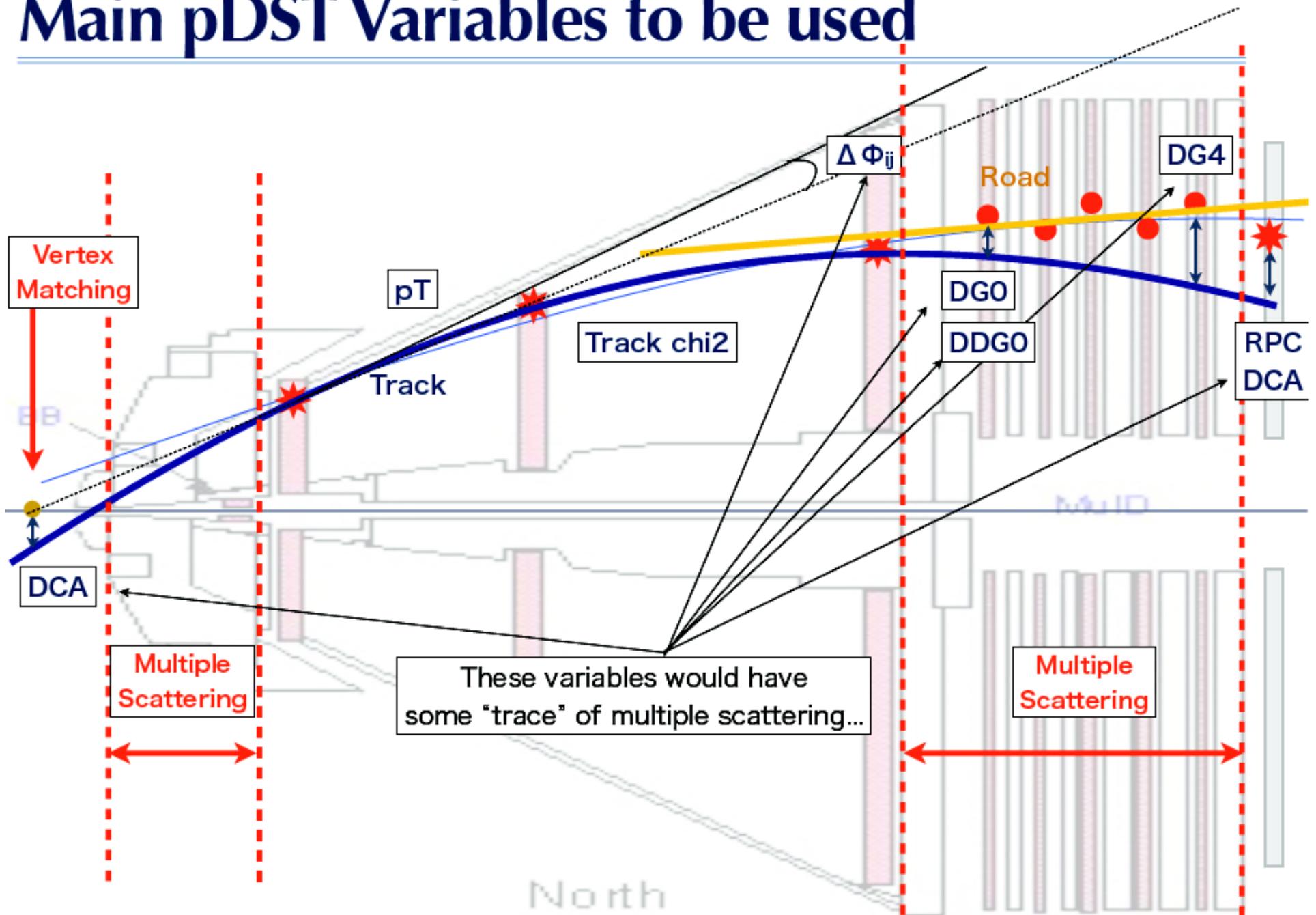
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Run12pp510 BBC Rate (Hz) vs Run Number

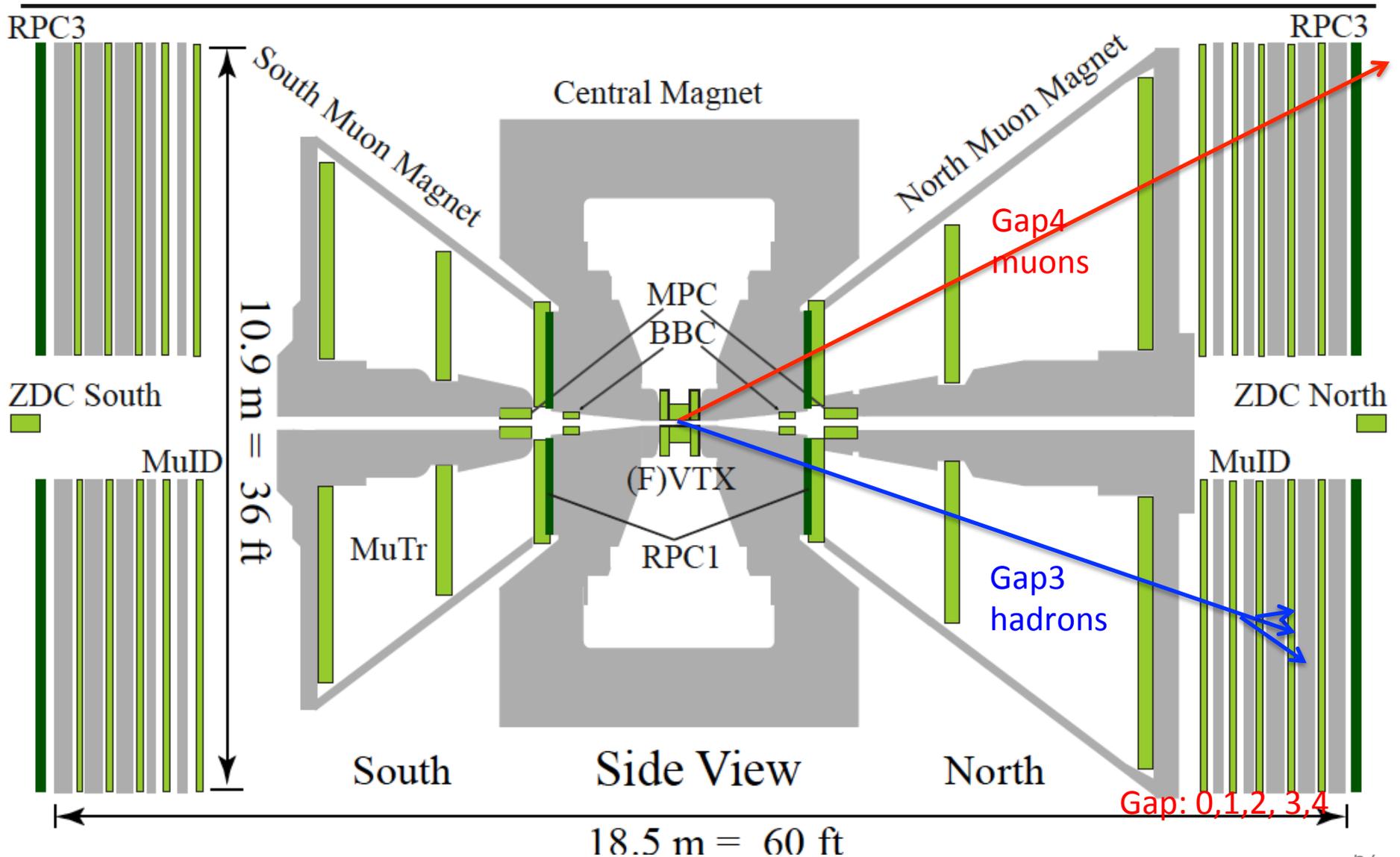


generic_runlist_highlumi.txt 108 runs BBC_rate>2.4MHz
generic_runlist_midlumi.txt 129 runs, in between
generic_runlist_lowlumi.txt 81 run3, BBC_rate<2.0 MHz

Main pDST Variables to be used



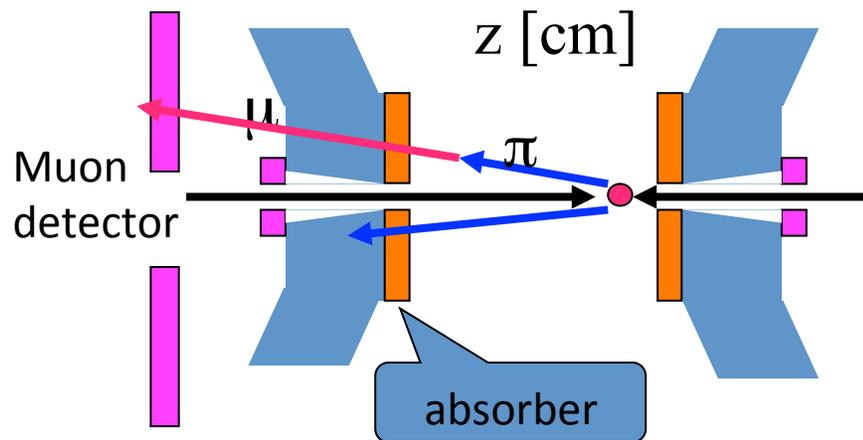
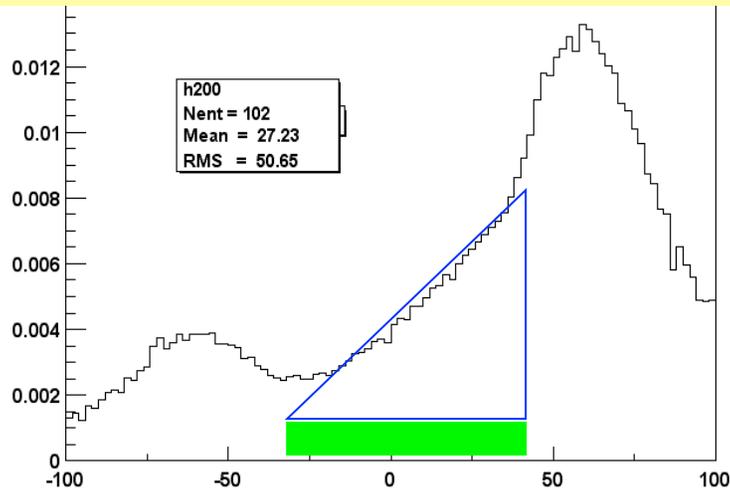
Reconstructed “Muons” tagged at various Gaps stopped hadrons and muons



The Old Tricks

Light Hadron Decay, Punch-through and Normalized Evt_Zvtx Distributions

Normalized South Muon Event Z vertex



- Muon yield increases as a function of distance from the absorber - due to muons from π/K decays

- Linear shape of z vertex slope, because $c\tau\gamma \sim 100$ [m].

- Prompt μ and hadron punch-through create the constant distribution in vertex.
 - MC sim
 - F/VTX DCA_r (new)